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Focus on:
Infra-red data transmission

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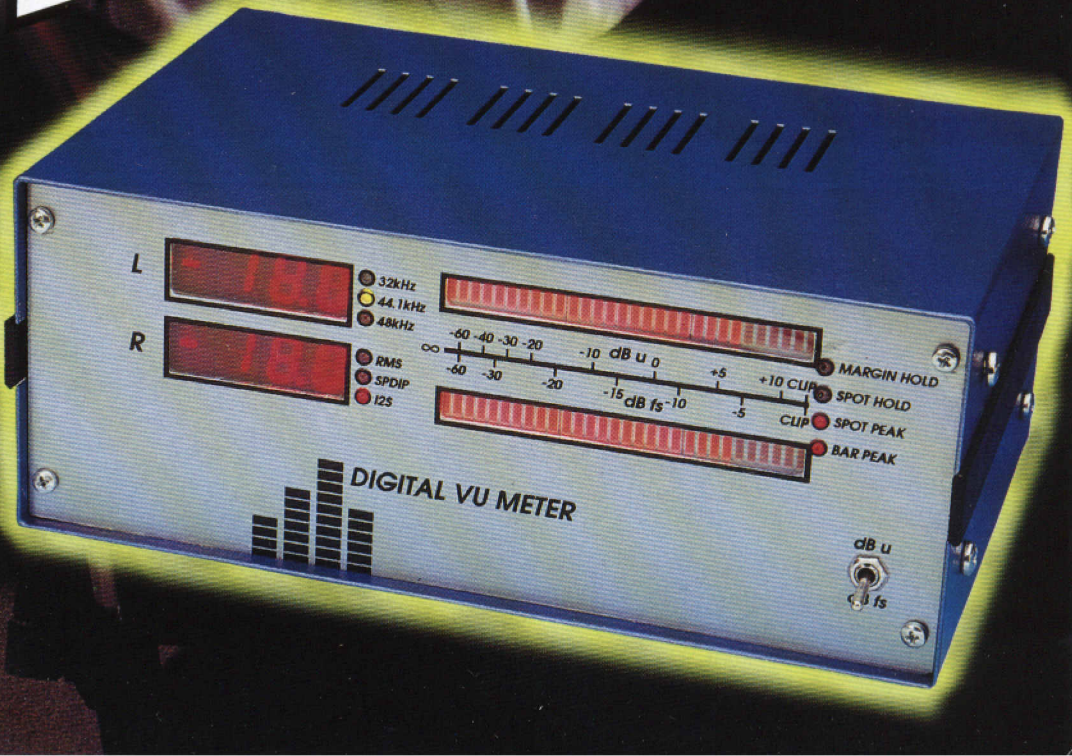

U2402 BATTERY CHARGER

CENTRONICS INTERFACE

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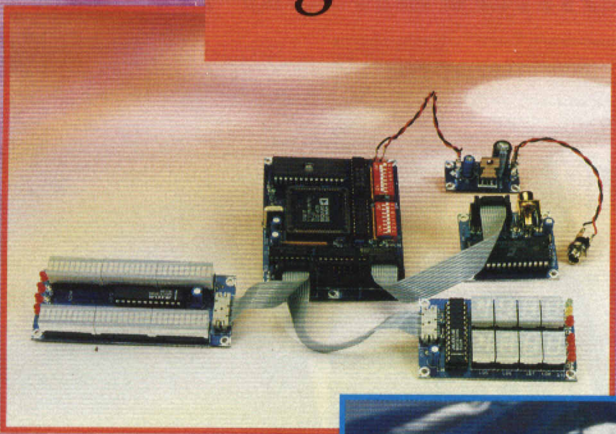

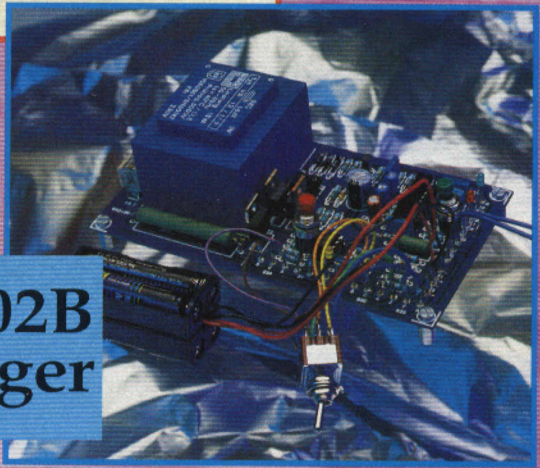

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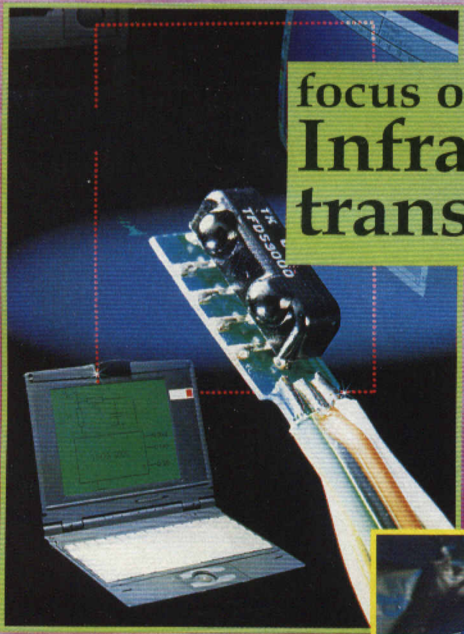

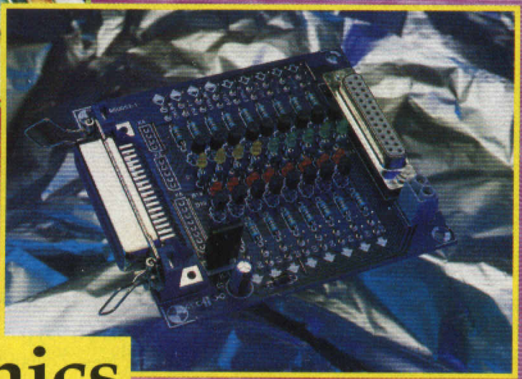

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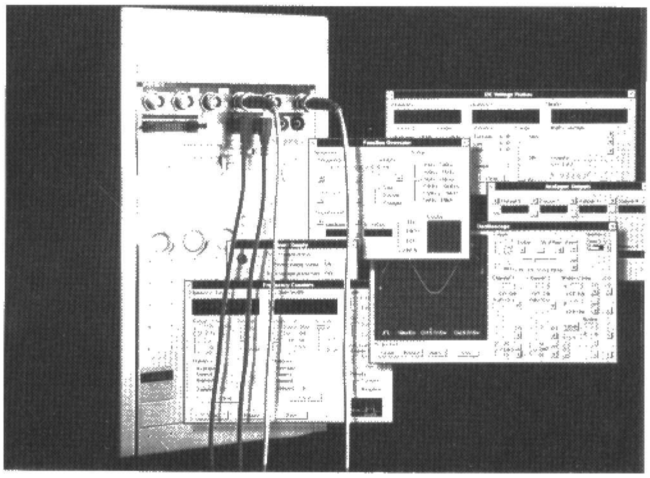
straightforward complex

Awards highlight design achievements



Toby Churchill Limited is typical of the many small science-based companies which are successfully growing in and around the university town of Cambridge. Recently, its work in designing and making portable text-to-speech communications aids was rewarded by success in Britain's Queen's Award for Export Achievement.

The major difference between Toby Churchill and other high-tech companies is that its founder is himself speech-disabled. Toby Churchill was a young engineering student when he contracted encephalitis after swimming in a polluted river. He lost his powers of speech and much of his mobility. After completing his degree course by correspondence, he began to think about how he could help himself. He believed something better could be devised than the alphabet keyboards which were then the only aids available for people who could not speak or who were speech-impaired.

He made his first machine in 1972 and formed Toby Churchill Limited in 1974. He owed his initial success to a willingness to hard work and by virtue of teaching himself the necessary computer and software skills. Later he recruited a team of co-workers to develop and make a suitable product for the market.

The result was a range of dual display machines with a choice of three qualities of speech synthesis. The machines can be used alone or in conjunctions with printers, fax machines and telephones. Word prediction, a standard feature, includes the 4000 most frequently used words in spoken English and is said to give a worthwhile reduction in key strokes even when producing short sentences.

Since they are text-to-speech devices, the use of the Churchill machines requires some degree of literacy. Many users suffer from speech loss following surgery, head injury or stroke. Others have progressive neurological disorders such as Parkinson's disease or motor neurone disease. Some suffer from congenital speech loss because of disorders such as cerebral palsy.

Easy to use

The machines are very easy to use: you simply turn them on and type. One of their best features is dual display, which allows people to converse in a natural face-to-face position. There is also a dual keyboard machine for use when conversing with someone who is profoundly deaf.

The Churchill machines are designed to be adaptable to other disabilities which sometimes occur with speech loss. These include poor motor control, tremor, weak muscles, slow reaction and impaired vision.

Often, such disabilities are met by the use of the company's scanning model, which can be incorporated by someone whose movement is limited or whose motor control does not allow successful operation of a keyboard. The scanning model is also suitable for a person who has some degree of sight loss as well as limited movement. It displays bold enlarged letters and

Electronics working for the speech-disabled

gives a choice of screen contrasts.

Operation can be by means of a wide choice of switches to allow for various kinds of disability. These include simple click switches, a zero-force touch switch, a foot switch and a suck/puff switch. Quadriplegics can use an eyeblink device which incorporates an infra-red beam mounted on dummy spectacle frames. The eyeblink switch will operate page turners and environment controls as well as the scanning machine.

Word predictions

The scanning model has a series of so-called pages. The first shows the alphabet, all the frequently used functions and up to four word predictions. If none of the predicted word are correct, the user can select additional letters to change the list of predicted words until the desired word appears. Other pages show numbers and additional punctuation and allow quick access to a range of setups and other functions, one of which allows two conversations to be held at once.

A further refinement is auditory scanning, which uses a scale of beeps for letters or function selection, or alternatively a speech facility will speak each letter, function or predicted word.

In 1993, Churchill made an agreement with Digital Equipment Corporation which provided for the integration of Digital's DECtalk speech synthesizer in Churchill's products. The introduction of DECtalk has increased sales in the American market. In 1990, interface with foreign language synthesizers became a reality and Churchill began to move into European and Scandinavian markets.Electronic Design Automation (EDA) is being increasingly used with great advantage in British industry. This fact was firmly established by the entries for the 1995 British Electronics Design Awards—BEDA.

Sponsored jointly by the magazine *Electronics Times* and the British design tool supplier, Mentor Graphics, the awards were established to raise the awareness of electronic design automation and to evaluate the benefits gained from the use of EDA tools. Entries were judged by the manner in which EDA techniques were used rather than any product resulting from their use.

Judging was in three categories: application specific integrated circuits (ASIC); Printed Circuit Boards (PCB); and electromechanical design.

Overall winner was Computing Devices whose entry in the ASIC section consisted of a design for a graphics manipulation chip for use in moving map displays. The electromechanical design winner was Tintometer Ltd for a liquid colour measure unit that incorporates electronics, mechanics and optics, while the winner of the PCB division was Motorola Communications and Infrastructure Division for a cell-

In brief

Internet under fire in the UK ...

Only a third of companies rate the Internet as effective, but appreciably more than a half think it a waste of time. These are the findings of a recent survey commissioned by The International Visual Communications Association in association with Sony.

'Surfing the Net' may even be responsible for decreasing productivity.

The survey is in contrast to claims made by the information industry (who, in general, have a vested interest in the Internet).

in Germany ...

It appears possible for a country (in this case Germany) to stop readers in any other country reading certain items on the Internet: in other words, to become the censor for millions of people who have nothing to do with that country. This is an outrageous infringement of people's freedom of expression and their right to access of information of whatever nature.

in France ...

France is proposing new international laws to curb certain information on the Internet. The move follows France's concern at the distribution on the Internet (*http://www. le-web.fr*) of a book, banned (!) in France, dealing with the long illness of former president Mitterand.

in the USA ...

According to the International Data Corporation, IDC, up to a fifth of America's top 500 companies having Web sites, will have either closed them down or frozen their growth by January 1997.

The computer age?

A poll conducted by the Massachusetts Institute of Technology* has found that, to Americans, the most important invention is the car. The light bulb came second, followed by the telephone. The computer and aspirin were in joint fourth place, a long way behind.

* Lemelson-MIT Prize Program Poll.

phone base station PCB.

Electromechanical design winner, Tintometer Ltd, used readily available in-house software for the design of its liquid colour measure. The design represents a novel combination of electronics, mechanics and optics in a low-cost unit. It will measure the colour of such liquids as beer, varnish, oils and fats.

A standard computer-aided design (CAD) system was used for the mechanical drawings and three-dimensional visualization, and a standard PCB software CAD governed the PCB layout. Programming of the gateways was also achieved with standard tools.

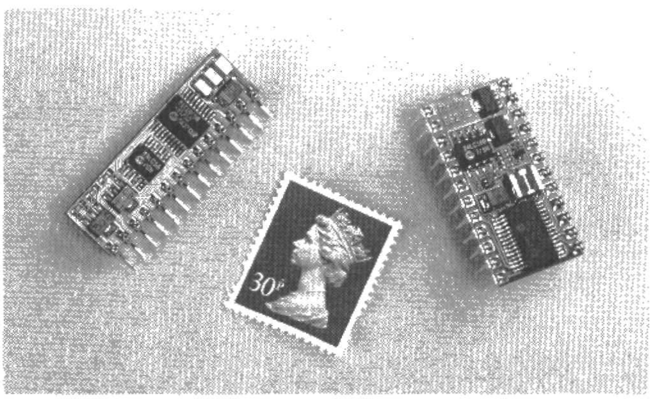
The problem of a low-cost light bench to house the PCB and various other components was solved by etching a thin brass sheet and folding it to form a box-like structure. By soldering the assemblies to the PCB sufficient strength was achieved to create a stable optical bench without the need for special jigs.

Motorola's winning PCB replaces the function of five boards previously used in the company's M-Cell Micro range of cellphone digital base stations. The board controls the radio frequency and performs digital signal processing in transmitted and received data.

Some idea of the complexity of this design can be gathered from the fact that one PCB had to accommodate eleven 208-pin digital signal processing chips, four ASICs, a 32-bit microcontroller and a 32-bit microprocessor.

In addition to the main awards, the BEDA judges gave a commendation to Siemens Plessey for the design of a digitally synthesized waveform generator.

BASIC Stamp Modules for the Macintosh



It has taken time, but the Stamp Modules are now available for the Macintosh—news that will delight the many academics, schools, universities, and scientists who use these computers exclusively.

The low cost and powerful features of these modules make them perfect for many prototyping and control applications. Their ease of programming means greatly reduced development time, yet allows specific features to be included.

Module 1 is a surface mount board with convenient 14-pin SIP connections that provides eight I/O lines. An on-board 256 byte EEPROM can hold up to 80 instruction lines and programs are executed at 2000 lines per second.

Module 2 is a 24-pin DIP format package that provides 16 I/O lines. An on-board 2 KB EEPROM can hold up to 600 instruction lines and programs are executed at 10 000 lines per second.

To write software for the Stamp Modules, you'll need the Programming Package, which contains editor software, programming cables, manual, extensive application notes and free technical support.

A project based on the original Stamp Modules for PCs was published in the May 1994 issue of this magazine.

Full details of the new modules for the Macintosh may be obtained from Milford Instruments, Milford House, 120 High Street, South Milford, Leeds LS25 5AQ. Telephone 01977 683 665. Fax 01977 681 465.

US telecomms deregulated

The US congress has approved a bill to deregulate telecommunications and control the spread of obscene material.

The bill, allowing greater competition between providers of telecoms services, is seen as the biggest change in the law in this sector for 60 years.

TV manufacturers will have to install a device enabling parents to control what their children watch.

Events in 1996

April

The **Sixth International Conference on AC and DC transmission** will be held at the Institution of Electrical Engineers (IEE) in London from 29 April to 3 May 1996.

May

8–9: The **Electronics Scotland Exhibition** at Gleneagles, Scotland.
21–23: The **Internet World** Exhibition in London.

June

4–5: The **ICET 96** conference on electronics technologies in Brighton, UK.

July

16–18: The **Semicon/West 96** exhibition and conference in San Francisco.

August

The **CeBIT Home** Trade Fair will take place at Hanover, Germany on 28 August to 1 September.

September

2–8: The **Farnborough Airshow** at Farnborough, UK.

October

8–10: The **Euro-EMC** exhibition at Sandown, UK.
18–27: The **Connect 96** consumer electronics show at the NEC, Birmingham.

November

12–15: The **Electronics 96** exhibition in Munich, Germany.
26–28: The **Manufacturing Week** Exhibition at the NEC, Birmingham.

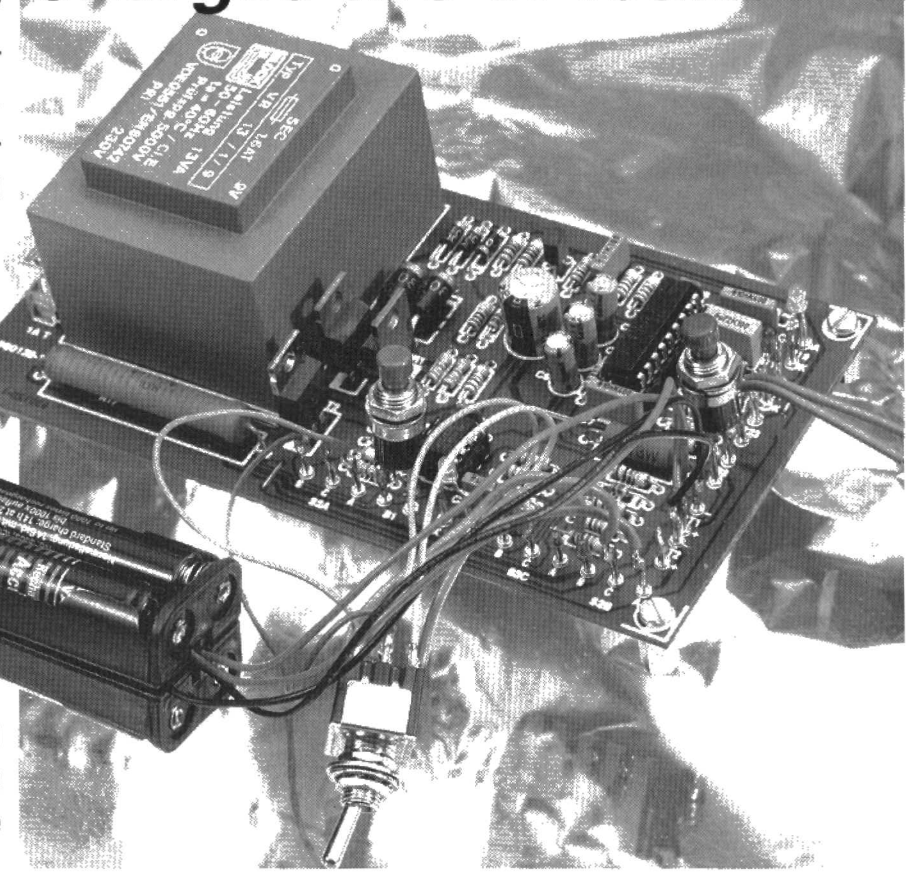
December

8–11: The **International Electronic Devices Meeting** in San Francisco.

U2402B battery charger

Charges two or four cells

Rechargeable batteries are environmentally friendly and cost-effective in everyday use. Moreover, they are well-behaved as long as you have enough time to charge them at an easy rate. Fast charging, say, within the hour, is a different kettle of fish, and should be done with care. The charger described here couples speed with intelligence, and knows how to deal with any eventuality which might occur during the charging process.



Charging with a current of about one tenth of the nominal battery capacity is still the safest way by far when it comes to handling NiCd (nickel-cadmium) or NiMH (nickel-metal-hydride) batteries. A slow charging process obviates any risk of overcharging, allowing the charger circuit to be kept as simple as possible. The disadvantage is that patience (hard thing!) is required before the battery is topped up again, because that takes between 14 and 15 hours.

If you think that is too long, there is no alternative but to invest in a fast charger. However, just a current source which pumps a lot of current through the cell(s) is grossly inadequate, as that creates the immediate risk of overcharging or, worse, damage to the cells.

Basically, there are two approaches to designing a 'safe' rapid charger. It is possible to start from an accurate current source for a well-defined charging current, in combination with an equally accurate timer which controls the total charging time. This works provided the cells are completely 'flat' when the charging cycle is started. If not, the cells are overcharged with a dangerously high current. Such a charger must, therefore, be equipped with an automatic discharging circuit which is sure to remove to any residual charge from the cells before they are charged. Admittedly, some energy is wasted in this way. Although a complete discharge is the best way to prevent the so-called memory effect in NiCd cells, that is not really necessary every time the battery is charged. As an effective counter measure against the memory effect, it is sufficient to discharge the cells completely once in ten charging cycles. NiMH batteries, by contrast, are completely free from any kind of memory effect. With these batteries, discharging before charging is really a waste of energy.

The second approach requires neither a timer nor a discharger. It does, however, call for a very accurate detection of the cell voltage. The trend of this voltage then enables the charge state of the cells to be deduced. Provided such a charger is properly designed, it is possible to switch off the charging current (or reduce it) the instant the cells are full, irrespective of their charging condition at the start of the charging cycle. The U2402B battery charger described in this article operates on the latter principle.

Nearly everything in one IC

These days we are so spoilt by modern integration technologies that nobody will be surprised to learn that nearly everything needed to build the previously described battery charger is contained in a single integrated circuit. We are referring to the U2402B from Temic (Telefunken Microelectronics, Germany). The main design parameters and specifications of this 'fast charge controller' IC may be found on the

Based on an idea by T. Lorenz

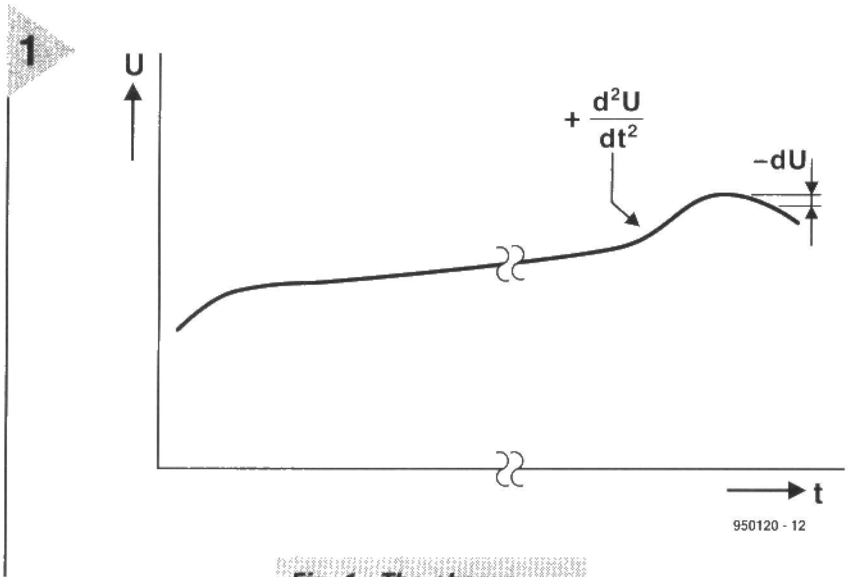


Fig. 1. The charge voltage curve is carefully monitored to prevent overcharging the cells. Just before the cells are fully topped up, the steepness (rate of rise) of the curve increases. This change is detected, and the charging current is drastically reduced. On detecting the slight droop at the end of the curve, the charger switches to trickle charging.

Elektor Electronics datasheet extracts elsewhere in this issue.

The U2402B is capable of charging cells with current pulses which last about 20 seconds. The time between these pulses is used to perform measurements. As far as external parts are concerned, the U2402B only needs a current source and a handful of passive parts. All functions which are essential to a reliable rapid charger are available in the U2402B:

Voltage guard

This is achieved in two ways as illustrated by the charge voltage curve shown in **figure 1**. A clever algorithm is applied to detect the faster rate of rise which occurs in the charge voltage curve just before the cells are fully charged. The actual switching point is defined by the second derivation $+d^2U/dt^2$. From that moment onwards, the charge current is drastically reduced to about ¼th or ⅜th of the nominal value, depending on the exact IC type. This is done to prevent heavy overcharging and the risk of gas developing in the cells.

The IC also detects the voltage drop which occurs in the curve when the cells are completely topped up (-dU). From then, the charger switches to trickle charging.

Temperature guard

An (external) NTC (negative temperature co-efficient) resistor is used to monitor the temperature of the cells. The charge function of the U2402B is disabled when a cell temperature outside the range 10°C to 40°C is measured.

Charge current regulation

The U2402B features a control circuit which is capable of setting an (external) current source to the appropriate charging current. This control operates very accurately. Here, an average charging current of 750 mA is used, so that the charger is suitable for cells with a nominal capacity of up to 750 mAh.

Dissipation limiter

Because phase angle control is used on the input voltage to maintain a constant charging current, the heat dissipation in the current source circuit is kept within acceptable limits.

Indications

The IC is capable of driving two LEDs which provide a continuous indication about the progress of the charging cycle.

As you can see, the U2402B is a pretty complete and state-of-the-art battery charger. The only missing feature is a discharging circuit, and that is all we have added to the IC, apart from the usual external parts, of course. This discharging circuit also has an LED indicator, and may be started by pressing a button. The charger switches automatically from discharging to charging.

Practical circuit

The complete circuit diagram of the fast charger is shown in **figure 2**. The circuit is designed for penlight (AA size) cells with a nominal capacity of up to 750 mAh. Switch S2 selects between charging two or four of these cells connected in series.

The circuit may be divided, broadly, in three sections. The 'brains' of the charger are formed by the U2402B (IC2) with its surrounding components. In fact, you are looking at the standard application circuit suggested by the manufacturer, Temic. LEDs D10 and D11 provide the charging status indication, while NTC R23 acts as a sensor for the cell temperature.

The upper section of the circuit diagram shows the power supply, a part of which functions as a controlled current source. That is achieved by adding two thyristors, Thr1 and Thr2, to the rectifier bridge. These devices provide phase angle control of the transformer voltage, and their operation is controlled by IC2. Diodes D1 and D2 ensure that the supply voltage for the circuit is not affected by the current source.

Finally, the left-hand section of the circuit diagram shows the added discharging circuit, whose main components are voltage guard IC1a, switch T2 and load resistance R17. The discharging cycle is started by pressing button S1. LED D17 provides a visual indication of the process.

It should be noted that the symbols Bt1 and Bt2 each represent two series-

Go for the right type!

Since introducing the U2402B, Temic have released a number of successor types. Unfortunately, the existence of these new versions may give rise to confusion and frustration. The oldest version, designated U2402B-A, does not work in the charger described here because it uses a different voltage detection method. Although production of the –A version was stopped some ago, left-over batches may be around which pop up in the electronics retail trade.

The types that may be used in the present charger are identified as U2402B-B and U2402B-C. These differ only in respect of the amount of reduced charge current and trickle current. The -C type also features a slightly improved A-D converter, and that may be why it gave the better performance in our prototype. While the -B version gave a fair number of early interruptions of the charge process, this annoying effect occurred less frequently with the -C version of the chip.

Incidentally, early interruptions are easily corrected by pressing S3 to reset the U2402B. The charge process is then finished without problems.

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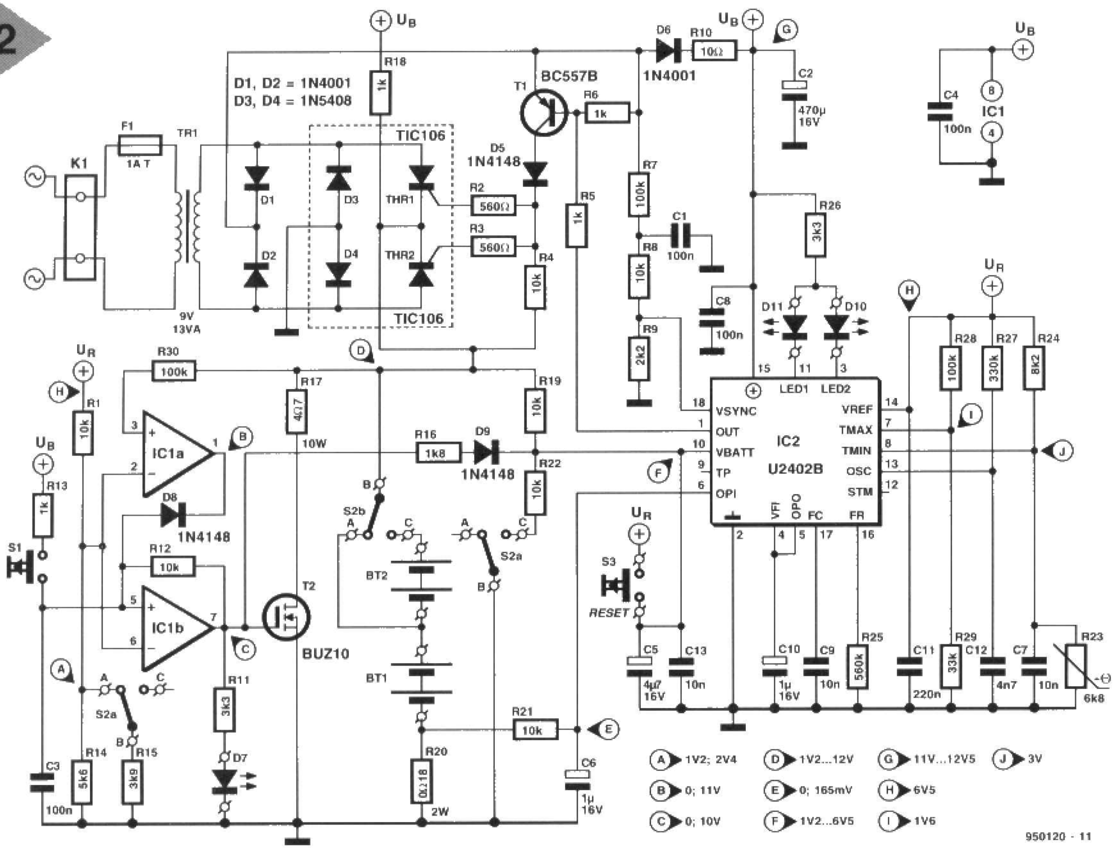

Fig. 2. Circuit diagram of the fast NiCd/NiMH charger. Switch S2 allows you to select between two or four series-connected cells, while S1 switches on the discharging function. The reset push-button, S3, enables the circuit to be started again after an early interruption of the charge process.

connected cells (batteries).

That completes a cursory discussion of the circuit diagram. Because many readers will want to know a little more about the design, the operation of some of the circuit sections will be discussed in greater detail below.

Current source

The rectifier is controlled by the U2402B, and provides the right charging current. As a matter of course, the control circuit operates on the basis of the current flowing through Bt1 (and Bt2). This current is measured by a small resistor, R20, which is connected in series with the cells.

The voltage across R20 is averaged with the aid of R21 and C6, and then applied to pin 6 of the U2402B. The drive signal for the thyristors in the bridge rectifier is adapted on the basis of the voltage at pin 6 until the voltage across capacitor C6 is virtually constant at 160 mV. That value corresponds to an average charging current of 888 mA. This value is purposely higher than the 750 mA we mentioned earlier. Remember, however, that the U2402B charges the batteries for about 20 seconds (actually, 20.28 s), and then inserts a pause of about 2.5 s to measure the cell voltage. The upshot is that the effective, average, charging current comes close to 750 mA.

While charging with reduced current, or with trickle charging, the voltage across R20 is still held constant at about 160 mV. The lower charging current is then achieved by a change in the charge/measure time ratio.

As already mentioned, the average current through the rectifier bridge D3/D4/Thr1/Thr2 is determined by the phase angle at which the thyristors are triggered, and the angle is determined by IC2. Transistor T1 and diode D5 form the external part of the trigger circuit. IC2 contains a sawtooth wave generator whose frequency and phase equal those of the double-phase rectified mains voltage. Consequently, the length of the trigger pulse equals the time the sawtooth voltage exceeds the voltage across C6. The speed of the control loop is determined by capacitor C10.

Voltage guard

The voltage across the cells connected to the charger is first smoothed to some extent by R19 and C5. Next, it is applied to the combined monitor/detection input of IC2. With switch S2c set to position 'C', R19 and R22 form a voltage divider which allows the voltage level to be adapted for the value of two or four series-connected cells.

The U2402B sports an on-chip ADC (analogue-to-digital converter) which consists of two cascaded 5-bit DACs (digital-to-analogue converters) – one for the coarse, and one for the fine set-

COMPONENTS LIST

Resistors:
R2,R3 = 560Ω
R1,R4,R8,R12,R19,R21,R22 = 10kΩ
R5,R6,R13,R18 = 1kΩ
R7,R28,R30 = 100kΩ
R9 = 2kΩ2
R10 = 10Ω
R11,R26 = 3kΩ3
R14 = 5kΩ6
R15 = 3kΩ9
R16 = 1kΩ8
R17 = 4Ω7 10W
R20 = 0Ω18 2W
R24 = 8kΩ2
R25 = 560kΩ
R27 = 330kΩ
R29 = 33kΩ
R23 = NTC 6kΩ8, type K164/68k/+, order code B57164-K683-+ (Siemens)

Capacitors:
C1,C3 = 100nF MKT
C4,C8 = 100nF Sibatit (Siemens)
C2 = 470μF 16V radial
C5 = 4μF7 16V radial
C6,C10 = 1μF 16V radial
C7,C9 = 10nF MKT
C11 = 220nF MKT
C12 = 4nF7 MKT
C13 = 10nF Sibatit (Siemens), mounting details: see text

Semiconductors:
D1,D2,D6 = 1N4001
D3,D4 = 1N5408
D5,D8,D9 = 1N4148
D7,D10,D11 = LED, high efficiency
T1 = BC557B
T2 = BUZ10
Thr1,Thr2 = TIC106D
IC1 = TLC272CP
IC2 = U2402B-C (or U2402B-B) (Temic)

Miscellaneous:
K1 = 2-way PCB terminal block, pitch 7.5mm
S1 = push-button, make contact
S2 = rocker switch 3 ¥ c/o at 5A
Tr1 = mains transformer, sec. 9 V/13 VA (preferred type: Block VR 13/1/9, alternative: Monacor VTR12109)
BT1,BT2 = battery holder for 2 penlight (AA) cells
F1 = fuse holder with cap and fuse 1A, slow
Enclosure, e.g., ESM type EC12/07FA
Printed circuit board, order code 950120-1 (see page 60).

ting. The maximum input voltage is 4 V, and the resolution is 6.5 mV according to the manufacturer. Although the total measuring time between charge pulses is 2.56 s, only the last 1.28 s are actually used. The first 1.28 s allows the cells to settle. The charge time of 20.48 s is also used by the ADC to perform its conversion operation.

Temperature guard

The cell temperature is monitored by NTC R23, which is fitted inside the battery holder. Together with R24, the NTC forms a voltage divider whose top terminal is connected to the reference voltage of 6.5 V at pin 14. The junction of the divider is connected to the T_{min} pin. The pin marked T_{max} is also connected to a voltage derived from U_r. Together with the NTC, the values of R24, R28 and R29 determine the size of the temperature window. Here, a range of 10°C to 40°C is selected.

Fig. 3. The printed circuit board has a fairly generous layout. The wire terminals are clearly labelled, and located at the edges of the board.

Discharging circuit

When the discharging function is started by pressing S1, the voltage at the positive input of IC1b rises to the supply level. Because the negative input of the opamp is at 1.2-2.4 V only, the output will also swing high, and remains high even after S1 is released, because of feedback resistor R12. Transistor T2 then starts to conduct, and the cells are discharged via resistor R17.

The discharging continues until the battery voltage has dropped to 0.6 V per cell. Next, voltage guard IC1a is actuated. This comparator compares the battery voltage with a reference voltage of 1.2 V or 2.4 V (2 or 4 cells, respectively), which is derived from U_r. This voltage is selectable with S2a, and conveniently doubles as the threshold voltage for IC1b. When the measured voltage drops below the reference voltage, the output of IC1a swings low. The input of IC1a is then pulled low via diode D8, so that this opamp toggles also. Next, transistor T2 is switched off, and the discharging cycle is stopped.

To prevent a useless charge current while the cells are being discharged, pin 10 of IC2 is held high by R16 and D9 during this period. The U2402B then assumes that there are no cells in the battery holder, so that the thyristors in the current source circuit are switched off.

Construction

Enough of theory, let's tackle the construction of the fast battery charger. The design of the printed circuit board for the charger is shown in **figure 3**. The board (which is available ready-made, see page 70) accommodates the entire circuit shown in figure 2 – that's including the mains transformer and the fuse.

Building up the board will not present unsurmountable problems. The layout is generous, and the component overlay leaves little room for confusion.

Start the construction as usual by fitting the low-profile parts: first, the five wire links, then the resistors and diodes, the capacitors, transistors, thyristors and, finally, the terminal block, the fuse holder and the transformer. IC1 and IC2 are fitted in IC sockets, but not before the entire construction has passed a thorough vis-

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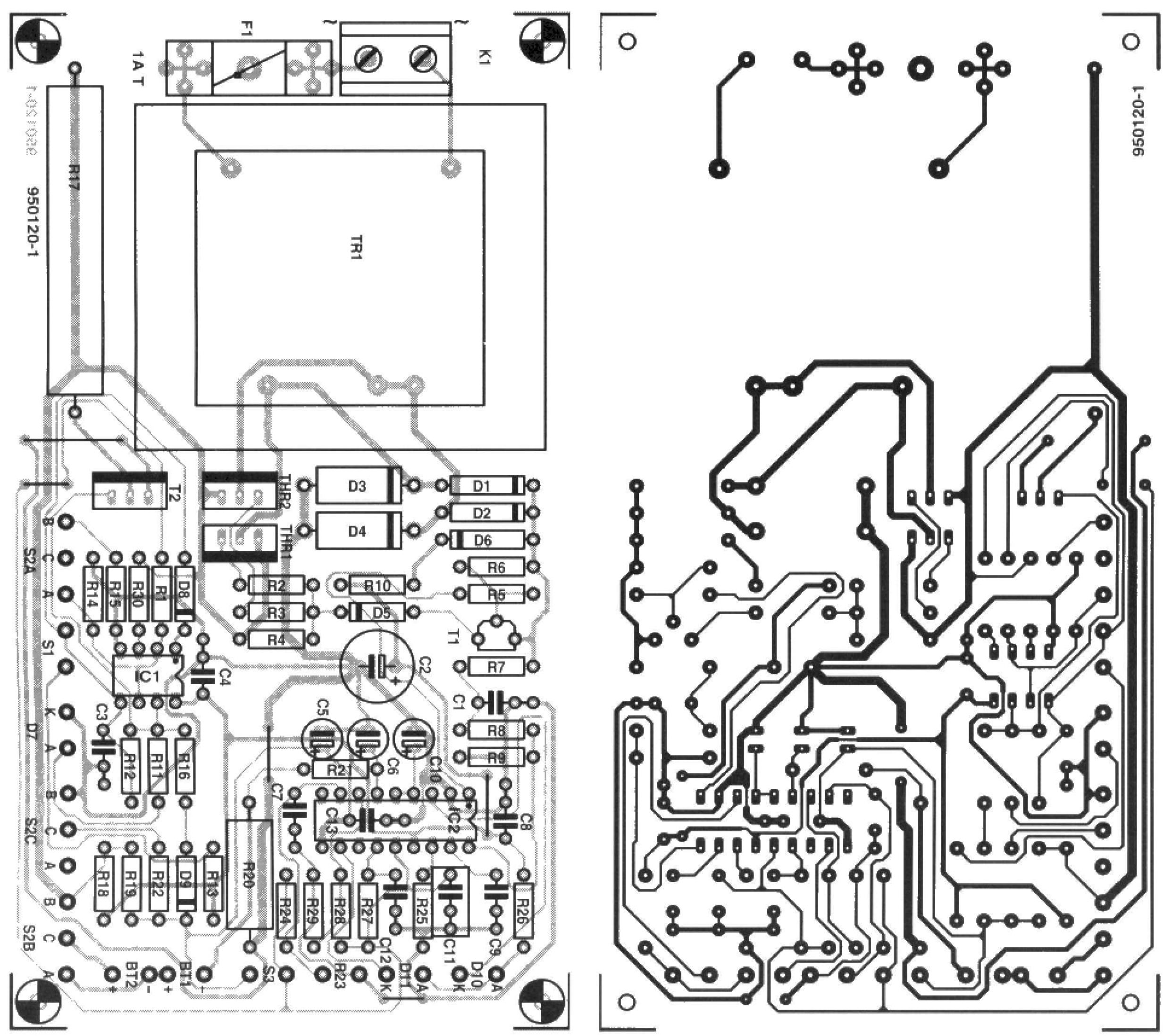


ual check. Pay attention to the polarity of the diodes and the electrolytic capacitors. As regards the thyristors, the white band on the component overlay corresponds to the metal part of the case.

A few more important remarks. Mount bleeder resistor R17 a few millimetres above the board. The resistor may run fairly hot during discharging cycles, and may damage the board if it is not fitted at a small height. Capacitor C13 serves to suppress fast noise pulses. It should be mounted as close as possible to IC2, and its wires kept as short as possible. To meet these requirements, a Siemens 'Sibatit' style miniature ceramic capacitor is used which is conveniently fitted in the empty space inside the IC socket. Alternatively, C13 may be fitted at the underside of the board.

Once the board is populated, it is given a final check. Next, connect the external elements via flexible wires: i.e., the switches, the LEDs, the NTC (R23) and the battery holder. The connecting pins for these elements are clearly printed on the board.

Next, put the cells in the holder, and set S2 to the correct position. Connect the charger to the mains, and use a digital multimeter to check the voltage levels indicated in the circuit diagram. If the deviations from the stated values are smaller than 10%, you may safely assume that the circuit works properly, and is ready for fitting into an enclosure.

The choice of a suitable enclosure for the U2402B battery charger is, in principle, free, provided a type is used with ventilation slots. These are necessary because the transformer and the load resistors do develop a fair amount of heat. If necessary, ventilation slots or holes may be drilled into an existing enclosure. The prototype was fitted into an enclosure type EC12/07FA from ESM.

As usual with mains-operated equipment in any type of case, great care should be taken to ensure that the mains entrance is solid. Also, the connection between the terminals on the mains appliance socket and K1, the screw-type terminal block on the board, must be properly isolated. The board is secured to the bottom of the case with the aid of 10-mm high PCB spacers. The LEDs and switches are, of course, fitted on the front panel, while the battery holder is mounted on top of the case.

The best position for the NTC (R23) is between the two cells, where it is secured to the battery holder by a drop of two-component glue.

Finally, fit a mains security label as shown below on the rear of the case, near the mains cable entry.

Practical use

The charger is extremely easy-going in everyday use. The only thing to keep in mind is that switch S2 must always be set to the correct number of cells **before** the cells are inserted into the holder. If you do not expect to ever use the charger for two batteries, then S2 may be omitted, and the relevant contacts interconnected permanently.

As soon as the cells are in the holder (use holder Bt1 if you charge only two batteries), the charger starts to charge immediately. No action is required on part of the user. Since the circuit continues with trickle charging after the main charging cycle, there is nothing to worry about if you happen forget about the cells, because they are automatically kept in top shape!

If, for some reason, the charge cycle is ended too soon, you may restart the circuit by pressing the reset button, S3.

To counter the memory effect which occurs with NiCd cells, it is wise to discharge them completely from time to time, if that has not been done by the equipment from which they are removed. Simply fit the batteries and press the 'discharge' button, S1. The charger switches to charging automatically after a complete discharging cycle.

LEDs D7, D10 and D11 tell you what the charger is doing at any time, as shown in **table 1**. Broadly speaking, LED D10 indicates that the cells are being charged, while D11 indicates that no charging takes place, and why.

(950120)

Table 1

Phase	D7	D10	D11
discharging	*on*	*off*	*flashes*
full charging	*off*	*flashes*	*off*
reduced charge/ trickle charging	*off*	*on*	*off*
Overheated	*off*	*off*	*on*
No/faulty cells connected	*off*	*off*	*flashes*

ELEKTOR	
230V ~	50Hz
No. 950120	
F = 1A T	

In passing ...

Controls on electronic equipment are like a key to the inside, and if we cannot turn the key fully, we cannot fully use the product inside the black box. To many consumers, the variety of setting techniques for watches, digital clocks, microwave ovens and video cassette recorders is bewildering.

Who has not fumbled in frustration to get some new electronic device to work? The experience of most of us is that once we have learned, by trial and error, the few moves to get the new clock to keep time or to get the video recorder to record and play, we leave it well alone: there is, in general, no further exploration of the controls. Thus, we have turned the key only partially. The door, as it were, is only ajar, not open.

Nevertheless, in spite of our frustrations with an incomplete mastery of electronic equipment, we continue to buy it in ever increasing quantities. In the West, most households have a microwave oven and a video cassette recorder, not to mention a camcorder.

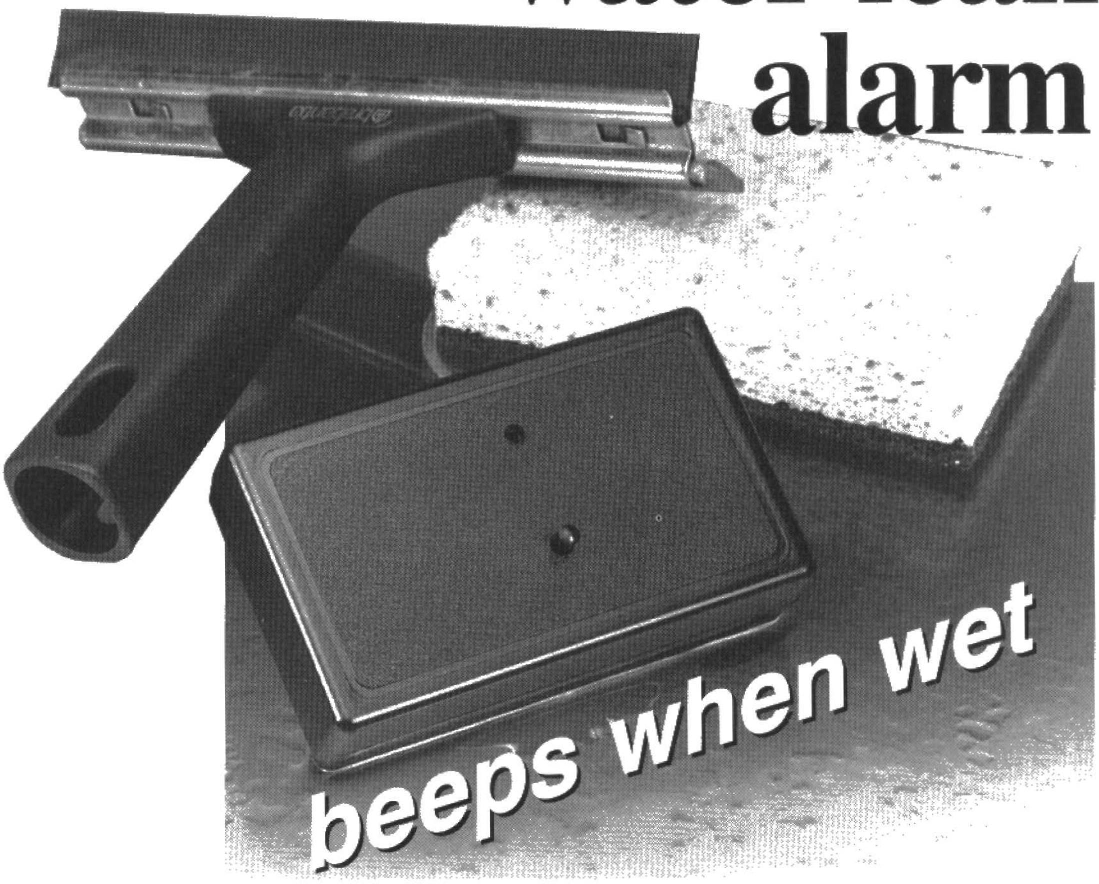
Ironically, many companies have begun to advertise their products as 'more user-friendly' and 'less sophisticated'.

We do not doubt the basic function of consumer electronic equipment. A digital watch is intended to tell the time, sound an alarm, and so on. A video recorder is to record programs while we are out or doing something else, and play them at a more convenient time. So why all the controls?

It is clear that electronics designers in general do not pay sufficient attention to the way their equipment will be operated. An American observer remarked not so long ago that "warning labels and large instruction manuals are signs of failure: attempts to patch up problems that should have been avoided by proper design in the first place".

Few of us would disagree with this. It does mean, however, that we continue to live in a technologically imperfect world and that we have little choice but to get used to its many (minor) irritations.

water leak alarm



beeps when wet

The circuit presented, although a simple design, guarantees a prompt and reliable indication of any form of water leak. It is hardly larger than a postage stamp and draws an almost negligible current. In short, an easy and inexpensive to build unit that can operate for years on a single 9 V battery.

Design by K. Walraven

It is to be hoped that nobody needs this circuit ever, because water leaks always cause a lot of misery, of which mopping up is the least. The present unit may prevent catastrophes, because a timely warning can make the difference between a leak and a flood.

What kind of circuit is it and how is it to be used? In ready form it is a very compact, plastic box that contains a small printed-circuit board, a buzzer and a battery. It does not need any external parts and is thus self-supporting. The screws fastening the PCB to the box protrude slightly through the bottom panel and so serve as sensors. The box is simply put on the protruding screws at the place that needs to be guarded: under newly installed central-heating pipes, under a boiler that is suspect, in the bathroom when the bath is being set, or, if you live near a stream or river, in the cellar.

When moisture accumulates under the box so that there is a conducting path between the 'sensors', the alarm is actuated and emits a piercing intermittent sound: a signal for immediate action! Since the circuit draws a current of $\leq 1\ \mu$A, an on/off switch is not required. This reduces the likelihood that you forget to switch it on when needed.

Because much may depend on the reliable operation of the alarm, it is provided with a test push button with which the readiness of the electronics and the state of the battery can be checked from time to time.

Just one IC

Figure 1 illustrates what has been said earlier: the circuit is a model of simplicity. It is, in fact, a combination of a sensor, two oscillators, and a buzzer. In reality, this comes down to one IC and a handful of passive components.

Points A, B, and C are sensor contacts connected to the protruding screws fastening the pcb to the box. As soon as there is a conducting link, caused by water, between A and B or between a and C, capacitor C_1 is charged slowly. Series resistors R_1–R_3 eliminate any effect of the static charge and also, in conjunction with C_1, provide interference suppression.

When C_1 has been charged to a level where the upper trigger threshold (about 5 V) of quadruple NAND Schmitt trigger 4093 is exceeded, the oscillator based on IC_{1a} starts. Pin 3 is then alternately high and low every 2.5 seconds, whereupon the 'beep' oscillator based on IC_{1b} is switched on and off in the same rhythm. This oscillator generates an intermittent beep at a frequency of about 1.25 kHz, which is passed via buffer IC_1 to buzzer Bz_1, which makes it audible. The two oscillators remain active until the potential

across C_1 drops below the lowest trigger threshold (about 3.5 V) of IC_1.

Test push-button switch S_1, when pressed, connects R_5 to the positive supply line, which has more or less the same effect as a conducting link between A and B or between A and C. If the switch is pressed for a few seconds, the buzzer should be heard clearly and loudly. If you hear nothing or only a weak beep, the battery needs to be replaced. It is good practice to test the battery in this manner once a month.

Diode D_1 forms a protection against connecting the battery with wrong polarity.

Capacitor C_4 decouples the supply line.

If the buzzer is required to sound louder, this can be arranged by increasing the 'beep' oscillator frequency from 1.25 kHz to 3 kHz (at which frequency the buzzer is most efficient). This is done by lowering the value of C_3 to, say, 4.7 nF.

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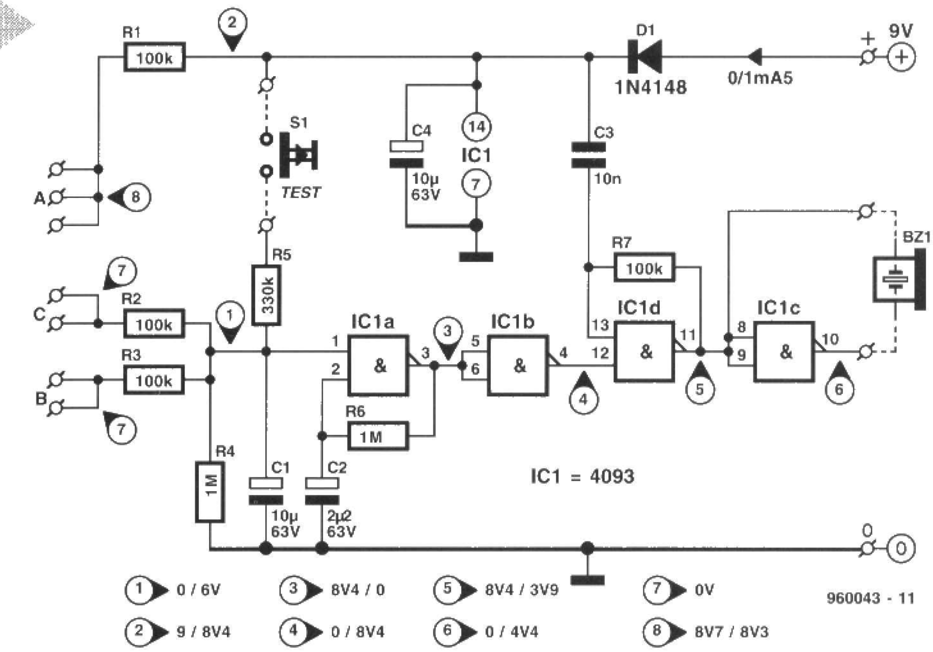

Figure 1. If there is a conducting link between contacts A and B or between A and C, an oscillator is enabled which causes the buzzer to emit an intermittent beep.

Construction

The alarm is best built on the printed-circuit board shown in **Figure 2**, which again shows what a simple circuit the alarm is. Populating the board is straightforward and should not present any difficulties. The fixing holes at the corners of the board are linked to sensor contact A, B and C. If metal screws are used to fasten the board to the box, the screwheads protruding at the bottom may function as sensors. In that case, any spacers between board and box must also be metal, of course.

In view of the small dimensions of the board, it should not be difficult to find a suitable plastic box in which to house the board, the buzzer and the battery.

The buzzer and test switch are best fitted in the lid of the box. An additional hole is needed in the lid to ensure that the buzzer can sound unhindered to the outside world.

The completed prototype is shown in **Figure 3**; experienced constructors will no doubt be able to make it even more compact—the circuit is small enough.

Testing

Although it is almost certain that the alarm will work first time when the battery is connected to it, the circuit diagram shows a number of voltages at given points, with which it should be simple to check the unit if it does not work. **Figure 4** shows where these test points can be found on the board.

Note that two voltages are given at the test points. The first of these is the level in quiescent operation and the second the level in active operation. The clearest example of this is test point 2 where the supply voltage is measured after diode D_1: the quiescent current is so tiny that it causes hardly any voltage drop across the diode, so that 9 V is measured. In active operation, the current is about 1.5 mA, so that a voltage drop of about 0.6 V ensues across D_1; the voltage at test point 2 is then 8.4 V.

Testing the unit is started with pressing S_1 for a few seconds; if this results in a clearly audible sound from the buzzer, the test points can be ignored, because it is virtually 100 per

Figure 2. Populating the board should not present any undue difficulties.

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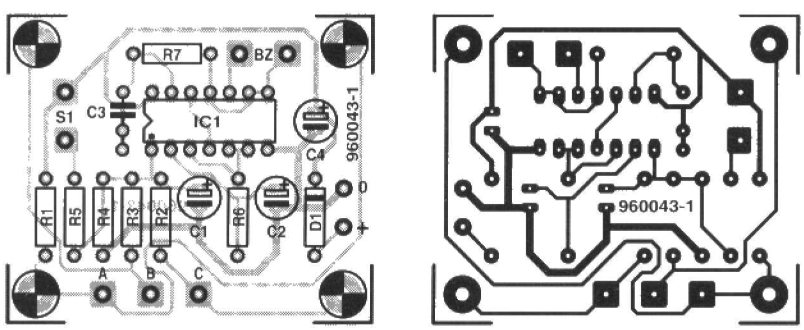

parts list

Resistors:
R_1, R_2, R_3, R_7 = 100 kΩ
R_4, R_6 = 1 MΩ
R_5 = 330 kΩ

Capacitors:
C_1, C_4 = 10 µF, 63 V, radial
C_2 = 2.2 µF, 63 V, radial
C_3 = 10 nF (but see text)

Semiconductors:
D_1 = 1N4148

Integrated circuits:
IC_1 = 4093

Miscellaneous:
S_1 = single-pole push button switch
Bz_1 = piezoelectric buzzer (Toko)
Bt_1 = 9 V battery
Plastic case, 61×22×80 mm (w×h×d)(2$^{13}/_{32}$×$^7/_8$×3$^5/_{32}$ in)

cent certain that the circuit functions correctly. If you want make quite sure, briefly short-circuit A to B or A to C; if there is no sound from the buzzer, the values of R_1, R_2, and R_3 are incorrect.

Let us assume that, improbable as it is, there is no sound from the buzzer after S_1 has been pressed for some seconds. It is then necessary to trace the signal path from start to finish. The only instrument needed for this is a high-impedance multimeter (most digital ones are suitable). Proceed as follows.

- Connect the meter in parallel with C_1, that is, between test point 1 and earth.
- Press S_1 and hold it down. The measured voltage should increase slowly to 6–7 V.
- If this is not the case, connect the meter between test point 2 and earth. If the measured voltage is also 0 V, it is almost certain that D_1 is connected with wrong polarity.
- If you measure the supply voltage (or thereabouts) at test point 2, there are three possibilities: (1) the value of R_5 is (much) too high; (2) the polarity of C_1 is incorrect; (3) the IC is defect. For security's sake, check the polarity of the other two electrolytic capacitors also.
- If the voltage at test point 3 (with S_1 pressed or sensor contacts short-circuited) is 6–7 V, connect the meter between test point 3 and earth. Here, the voltage should change every 2.5 seconds between 0 V and 8.4 V. The voltage at test point 4 is the same, but inverted with respect to that at test point 3. Any deviations from these values are caused by R_6 and/or C_2: this needs checking!
- During the time that the voltage at test point 4 is high, test point 5 carries the 1.25 kHz oscillator signal. This cannot be measured precisely with the multimeter, of course, but the meter will show an average value: it should alternate between 8.4 V and 3.9 V.
- The voltage at test point 6 is the inverted value of that at test point 5. If all these voltages are correct and there is still no sound from the buzzer, it is certain that the buzzer is defect.

(960043)

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Figure 3. The completed prototype (which could have been more compact). The fixing screws of the board function as sensors.

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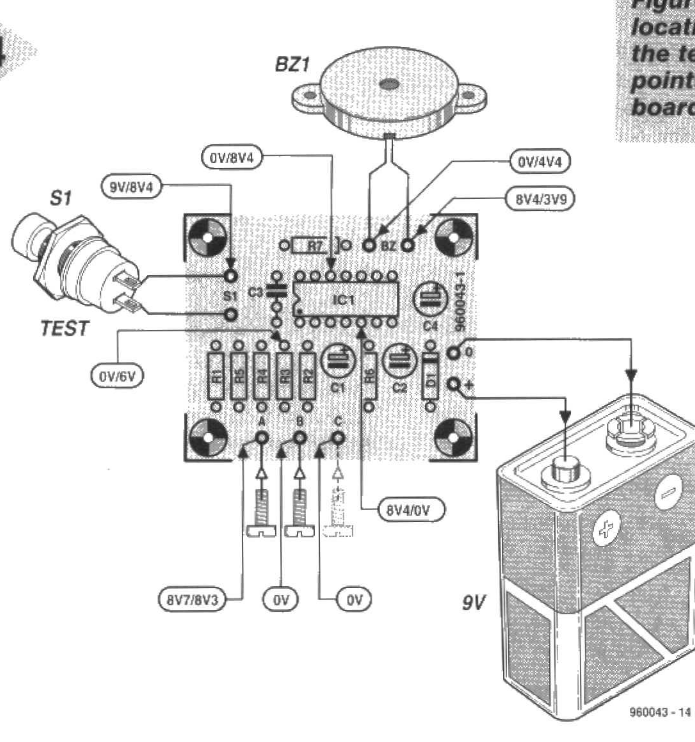


Figure 4. The location of the test points on the board.

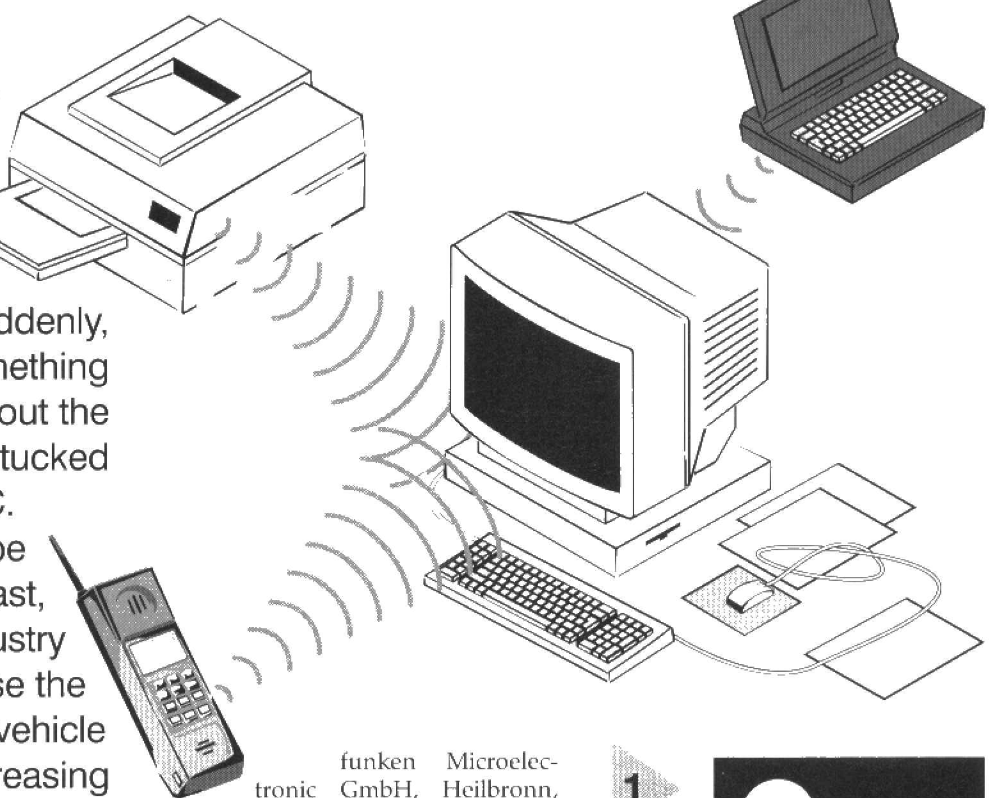
Hysteresis

The four gates in a 4093 are a combination of a nand gate and a Schmitt trigger. A nand gate is a digital circuit whose output is low only when all inputs are high. Typical of a Schmitt trigger is that its output changes state only when the level at its inputs exceeds a certain upper switching threshold, or when the level drops below a certain lower threshold. There is therefore a difference between the level at which it switches on and that at which it switches off. This difference, called hysteresis, prevents the circuit clattering backwards and forwards at a certain critical voltage. A room thermostat is a typical example of a unit in which some hysteresis is indispensable.

The exact values of the switching threshold of a 4093 may differ from manufacturer to manufacturer. In RCA (Harris) devices, they are 3.15 V and 5.4 V; in Philips models, 3.78 V and 4.2 V; in SGS versions, 3.51 V and 5.31 V. These differences do not affect the operation of the alarm, but they do affect the oscillator frequency to some extent. Again, in the alarm, this does not matter.

FOCUS ON: INFRA-RED DATA TRANSMISSION

By our editorial staff



Whether remote control, headphones or telephone, everything is cordless these days. Suddenly, there is something anachronistic about the heap of cables tucked away behind the PC. Well, it may soon be a thing of the past, because the industry looks poised to use the IrDA standard as a vehicle to replace an increasing number of serial ports by small infra-red modules which interconnect laptop PCs, desktop PCs, notebooks and organizers. The same IrDA modules then form a bridge to peripherals like printers, modems and telephone sets.

The acronym IrDA stands for Infra-Red Data Association. This advisory board bundles the forces of several manufacturers involved in data technology and optoelectronics. Their aim is come up with a standard for data exchange via infra-red light. Among the IrDA members of the first hour are Hewlett Packard (HP) and Temic (Telefunken Microelectronic GmbH, Heilbronn, Germany). Today, the propositions of the IrDA for a serial infra-red interface have become a quasi standard based on hardware developed by HP for their SIR (serial infra-red) interface.

The IrDA interface is particulary suitable for data exchange between laptop/desktop PCs and printers, telephone sets and fax machines. The advantage is not only the total absence of cumbersome cable connections, but also a considerable cost reduction (cables and plugs are expensive!), and, last but not least, a high degree of noise immunity. Apart from the inherent electrical isolation between transmitter and receiver, the immunity against electrical and magnetic fields should be mentioned (no EMC problems!). An IrDa link is also difficult to tap or bug because light is emitted rather than electrical current, electromagnetic radiation simply does not occur and can not be 'bugged'. In contrast with a radio-based link, the IrDA link is not subject to licencing by the DTI. Apparatus featuring an IrDA compatible interface may be identified with the IrDA trademark as shown in **Figure 1**.

1

960015 - 12

Fig. 1. This logo means that the equipment is IrDA compatible.

IrDA, a standard for infra-red communications

Point-and-Beam

The IrDA recommendation purposely specifies a relatively short range to ensure a low current consumption, and to prevent interference between different apparatus with an IrDA interface. The result of this recommendation is that the normal range is about one metre at a pointing angle of about 30° (±15°). The IR diodes used are low-cost devices transmitting in the 850 to 900 nm (nanometres) range. Light in this part of the spectrum is harmless for humans, and also present in sun-

light. Larger distances between transmitter and receiver are possible by increasing the radiation power and/or the receiver sensitivity. In any case, the directivity of the system requires you to point the transmitter at the receiver. In the IrDA literature, this principle is called *Point-and-Beam*.

The first IrDA proposition, IrDA-1 (1994), specifies a data exchange rate of 115.2 kilobit/s (kBaud) in half-duplex mode (i.e., no simultaneous transmitting and receiving). Since then, standards with baud rates of 4 Megabits/s and 1.15 Megabits/s have been issued. These 'fast IrDA' systems are downward compatible with IRDA-1. As far as technology is concerned, baud rates up to 10 Mbits/s should not be a problem. Some recently developed transmitting diodes even allow baudrates up to 30 Megabits/s to be achieved. There can be no doubt that the last specification makes IrDA interfaces suitable for future multimedia data exchange.

SHORT PULSES

As illustrated in the block diagram in **Figure 2**, an IrDA link is, in principle, based on extending an available serial interface (RS232 or UART) with an infra-red light emitting diode (IRED) connected up as a transmitter (light source), and a photodiode as a receiver (light transducer). Before transmission, the infra-red interface reduces the pulses supplied by the UART or RS232 driver to a maximum of 3/16th (18.75%) of the original bit length. In this way, the total power requirement of the transmitter is reduced by driving the IREDs with narrow pulses – obviously, reducing current drain is essential for applications in mobile equipment! The IrDA propositions specify a minimum pulse width of 1.6 µs, with a maximum rise time of 0.6 µs and jitter not longer than 0.2 µs (see **Main Specifications**).

At the receiver side, the IR interface restores the pulses to their original length, allowing them to be processed in the normal way by an RS232 interface or a UART.

INFRA-RED MODULE

Modules are available from a number of manufacturers for all regular IrDA applications. These modules are very compact, yet contain the IRED, IRED driver, photodiode, amplifier and comparator, all mounted in an SMA (surface-mount assembly) enclosure.

The type **HSL-1000** IR module is shown in different case styles to allow you to compare the size against that of regular IR LEDs. The different mounting options on a printed circuit board are illustrated in **Figure 4**.

The internal circuit of the HDSL-1000 and the necessary external parts are shown in **Figure 5**. The input of the module is driven with (shortened) serial pulses which are converted into infra-red light pulses by the IRED. At the receiver side, infra-red light pulses are detected and then converted into TTL pulses which are made available at the output. Not included in the module is the IR interface for the pulse length adaptation as required for transmitting and receiving.

Apart from high sensitivity, a large dynamic range is also paramount at the receiver side. In the HP module, that is achieved by an input amplifier/limiter with feedback. The daylight suppression is of particular importance because the infra-red range used is also present in sunlight and light emitted by electric bulbs. The transparent plastic case is given a colour which reduces the intensity of light with a wavelength < 850 nm. The narrow aperture of the receiver lens also helps to reduce interference by daylight and bulb light.

The input amplifier behind the PIN photodiode features a special co-light suppression stage which uses capacitor C_{x1} to filter out the co-light part in the signal. Furthermore, a coupling capacitor at the amplifier output ensures that only the alternating voltage component of the signal can reach the comparator.

RANGE

The fast transmitter LED is marked by high efficiency which, in conjunction with the wideband driver, enables infra-red light pulses with a high intensity and steep edges to be supplied. The anode terminal of the IRED (pin 8) is connected to the supply voltage via an external series resistor (R_{LED}) for the current setting. The IR transmitting power specified in the IrDA standard is already reached (and possibly exceeded) at a pulse current of 250 mA, which is defined with an R_{LED} value of 10 Ω. From this it follows that the voltage drop across the LED is of the order of 2.5 V in the typical current range (0.2 to 0.5 A). So, the LED current may be written as

$$I_{LED} = (V_+ - 2.5\ V) / R_{LED}$$

To make sure that the 250 mA pulse current remains available even at a supply voltage of 4.5 V, the series resistance

IrDA-1 Main Specifications

Distance:	1 m (3 m optional)
Viewing angle:	±15° (max. ±30°)
Baudrate:	9.6 to 115.2 kBaud (half-duplex)
Bit error rate:	$<1\times10^{-9}$
Wavelength:	850-900 nm
Max. pulse length:	3/16th of RS232 bit length
Min. pulse length:	1.6 µs
Rise and fall time:	max. 0.6 µs
Jitter:	max. 0.2 µs

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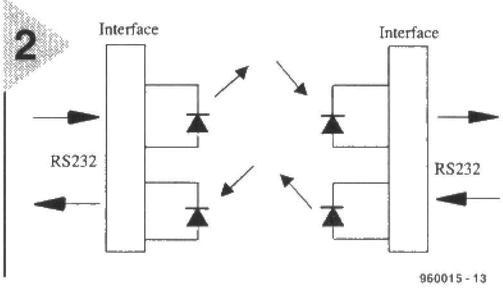

Fig. 2. Block diagram of an IrDA connection. An IrDA interface sits between an RS232 port and an infra-red (IR) transmitter/receiver.

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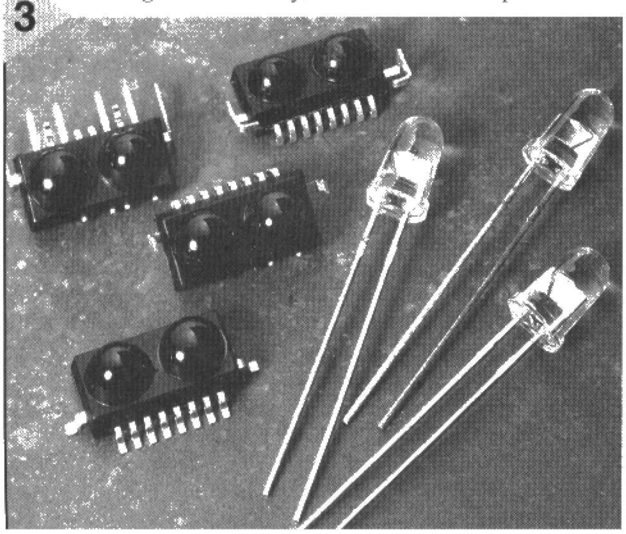

Fig. 3. Compare the size of HP's HDSL-1000 IrDA module with that of a couple of regular IREDs.

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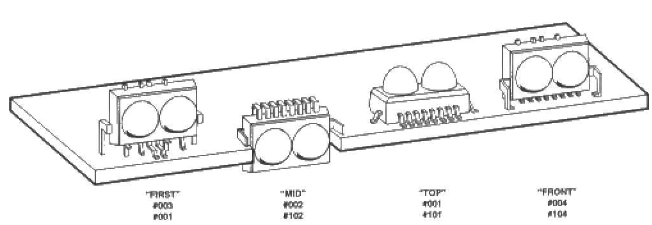


Fig. 4. PCB-mounting options of IR modules in SMA enclosures.

PIN photodiodes

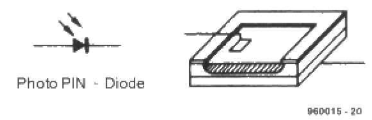
PIN photodiodes are a special brand of silicon photodiodes, built using planar technology. Nothing special in itself, however, because planar technology has been used for decades in the production of many (integrated) silicon semiconductor circuits and all photodiodes. The term 'planar' means that all production steps on a silicon waver are carried out in one plane. The main production phases are: epitaxy, oxidation, photolithography, diffusion and metal layer depositing.

With photodiodes, the edges of the p-n junction are in a protected position under the silicon-dioxide (SiO2) layer which is used as a diffusion mask. This layer is produced by oxidizing the silicon layer. The structure so obtained allows a low 'dark' current to be achieved (i.e., the reverse current that flows through the covered photodiode). The result is high sensitivity and the possibility to operate the diode at relatively high reverse voltages.

The special thing about PIN photodiodes is a large and high-resistance intrinsic (self-conducting) zone between the p and the n side. The designation of these devices is derived from the formal description of this layer: P_+IN_+. Free charge carriers clear the intrinsic zone at relatively low reverse voltages, when nearly all of the depletion layer is formed by the intrinsic zone. As a result, the reverse current is reduced while the sensitivity increases. At the same time, very short switching times are achieved (as with other PIN diodes).

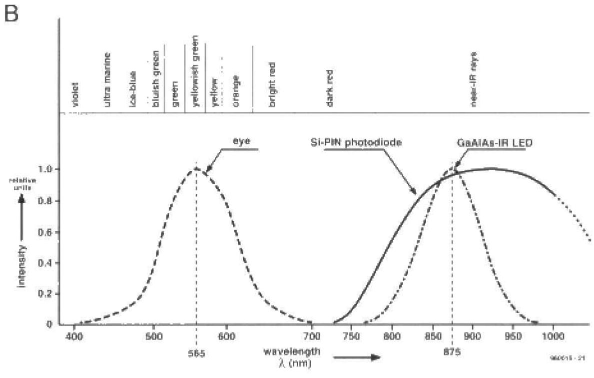
*The chip structure of a PIN photodiode is shown in **Figure A**. The use of PIN photodiodes is also advantageous at relatively low frequencies (baudrates). It is possible to use diode chips with a relatively large area, which still exhibit a very low capacitance. That, in turn, enables operation at low supply voltages and with high-value load resistors. The total result is a relatively high signal level.*

A



*Another advantage which is important for IrDA applications is the high sensitivity for infra-red light. **Figure B** shows the spectral sensitivity of a silicon PIN photodiode compared with that of a GaAlAs infra-red LED, as they are used for IrDA links. To make the comparison even more interesting, the dashed line shows the sensitivity curve of the human eye.*

B



should not be larger than 8.2 Ω. That value guarantees the IrDA range of 1 m, while up to 2 m may actually be covered in typical applications. To increase the range, the IRED pulse current may be increased. That must be done at both sides of the IR link, however. Increasing the pulse current to 500 mA gives a typical range of about 3 m (typical) or a guaranteed range of 1.5 m (baud rate up to 115.2 kB/s). Provided the duty factor remains smaller than 0.2, the IRED in the DSDL-1000 (max. continuous current 100 mA) may be pulsed at even higher currents. At the minimum pulsewidth of 1.6 µs and a data rate of 9,600 baud, a duty factor of only 0.0152 is obtained, which allows a pulse current of 1 A.

Another way of increasing the range is illustrated in **Figure 6**. because both terminals of the internal IRED are bonded out to pins, a second IRED may be connected in parallel. A high-efficiency IRED like the Hewlett Packard type HSDL-4230, pulsed at 250 mA, enables distances in excess of 4 m to be covered. When both LEDs are pulsed at 1 A (1.6-µs pulsewidth at 9,600 bits/s), distances up to 10 m may be covered.

Other modules

The type **TFDS3000** from Temic (**Figure 7**) is even smaller than the Hewlett Packard module. Remarkably, the input section of the TFDS3000 uses automatic gain control (AGC) instead of a limiter. Because it has a supply voltage range of 3 to 5.5 V, the Temic module is suitable for use in 3.3-V systems. This is possible by virtue of the lower voltage drop across the IRED (1.8 to 2 V at 250 to 400 mA). That creates the possibility to connect a second IRED **in series** with the internal IRED with the obvious aim of increasing the range. Doing so fully exploits the available supply voltage of 5 V. Obviously, at a supply voltage of 3.3 V the second IRED is connected in parallel rather than in series.

The types **IRM3001** and **IRM3005** are competing products from Siemens. Both IrDA modules are designed to operate at a supply voltage of 5 V, and only differ in respect of the SMA case they are supplied in. Their size, 13×6×5 mm, is almost the same as that of the Temic module. The Temic and Siemens IrDA modules offer a shutdown function which serves to reduce the current consumption in standby mode. This is particularly useful in mobile equipment. Hewlett Packard also offers a 3-V IrDA module with a shutdown function: the **HDSL-1001**.

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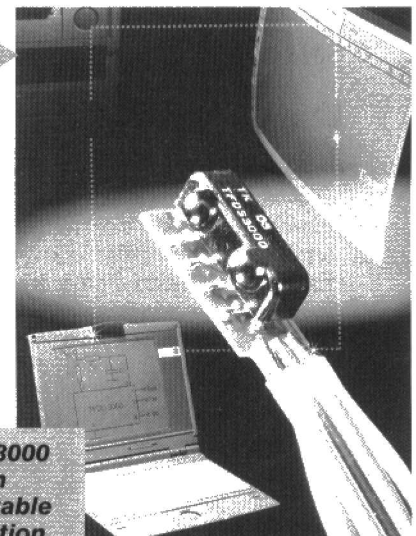

Fig. 7. The TFDS3000 IrDA module from Temic is also suitable for 3.3-volt operation.

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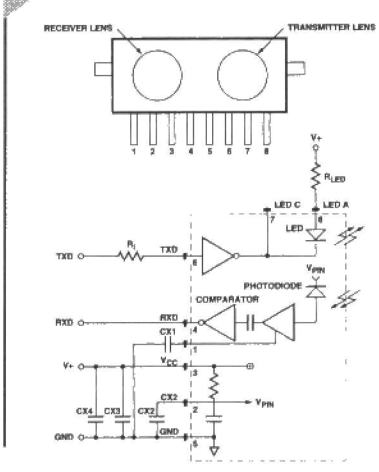

Fig. 5. Internal schematic of the HDSL-1000, plus the necessary external parts.

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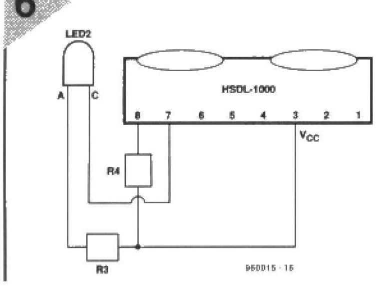

Fig. 6. Parallel connection of an external IRED to obtain a larger transmitter range.

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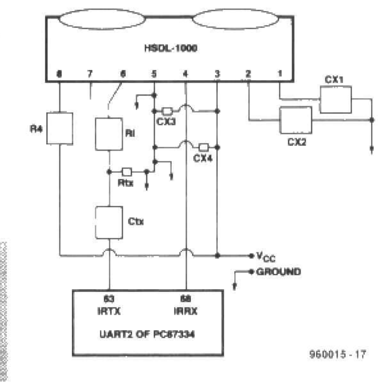

Fig. 8. Infra-red modules may be connected directly to Super-I/O building blocks like the PC87334.

Interfacing

The interface remains very simple if the host system (computer, laptop or peripheral) features a so-called *Super-I/O Controller* like the **PC87334** from National Semiconductor, the **FDC36C665IR** or **FDC37C666IR** from SMC. Typically found in desktop PCs and notebooks, these multi-I/O blocks already offer an infra-red interface for easy connection to an IrDA module.

With reference to **Figure 8**, the pins designated IRTX and IRRX of a PC87334 are connected directly to the input and output of a HDSL-1000 IrDA module. Inside the PC87334, UART2 is employed for the IR interface.

Another I/O building block with a built-in infra-red interface is the **ST16C654** from Startech/Exar. Remarkably, this module also sports a MIDI (musical instruments digital interface).

Of particular interest for this article is the recently introduced **PC87108VJE** from National Semiconductor. This brand new device offers no fewer than four IR function blocks. Only one of these is intended for standard IrDA modules. Two are designed to interface to fast IrDA modules operating at 1.152 MBit/s and 4 MBit/s, and the fourth one is Sharp DASK compatible (an IR link for some types of organizer etc.).

With UART and RS232

Connecting a UART like the 16550 to an IR module requires a separate IR interface integrated circuit which handles the pulse width adaptation. In **Figure 9** this function is performed by an **HSDL-7000** from Hewlett Packard. This configuration (HSDL-7000 and HSDL-1000) is also present on an SIR Evaluation Board supplied by Hewlett Packard (**Figure 10**). For the pulse lengthening function, which is dependent on the baud rate, the HSDL-1000 requires a frequency of 16 times the serial clock (baudot clock). This frequency is supplied by the UART.

Also designed to interface with HP's HSDL-1000 is the **ST84C01** from Startech/Exar. The Temic **TOIM3000** has a supply voltage range of 3 to 5 V and is optimized for interfacing with the TFDS3000.

Upgrading existing RS232 ports

A small problem arises if you want to upgrade an existing RS232 port with IrDA features. The pulse shortening/lengthening function mentioned earlier requires baud rate information. Unfortunately, the relevant clock signal has to be 'stolen' from the UART, which means that you have to open the computer or peripheral. The solution to this problem is to provide the IR interface with its own baudrate generator, whose speed is programmed by software via the RS232 interface. Furthermore, you will need a signal level converter from TTL to RS232 (for example, a MAX232).

A practical solution is offered by the Temic **TOIM3232**, which is basically an IR interface with a built-in baudrate generator. **Figure 11** shows the block diagram of this external IrDA adaptor for the RS232 interface, consisting of level converters, an IR interface and an IR module.

Outlook

Measured by the high expectations of the IrDA chip developers, the market penetration of these cordless infra-red links is modest as yet. The latest notebook-type computers, however, come with an IrDA interface as a standard feature. Driver software is not a problem, either. Use is made of an asynchronous half-duplex protocol called IRLAP. Originally proposed by IBM, this protocol was fine-tuned in co-operation with Hewlett Packard and Apple.

The IRLAP protocol is marked by a master/slave relation between a primary station and one or more secondary stations. The primary station status assignment is carried out when the link is initiated. In accordance with this protocol, Microsoft have released an IrDa driver wich is available via their Internet site. The exact address is **http://www.microsoft.com/windows/spftware/drivers/drivers/htm**.

It is expected that this driver wil be included with future releases of Windows 95.

In view of the popularity of portable communication (keywords: 'Handy' and 'Porta-'), the IrDA may make some important contributions. In the foreground is, of course, the business of networking of PCs, notebooks and peripherals. An IrDA PCMIA card and upgrade solutions for RS232 ports in the form of dongles are also significant in this respect.

Interesting application options become available for trade, home construction and industry. An example is the replacement of a car diagnosis plug by an IrDA interface which allows car computer data to be captured with the bonnet closed. In the consumer electronics field, IrdA is already suitable for interactive remote controls and data links with the PC. The high-speed IR standards to be introduced in the near future should also allow digital audio and video data to be conveyed without cables. Fast IR links also enable local IR networks (IR-LANs) to be implemented, or infra-red gateways to existing LANs.

There appear to be no limits to the application of fast infra-red technology in combination with multimedia digital stuff. As always, however, it remains to be seen whether equipment manufacturers and, more importantly, users, are prepared to actually make use of this vast potential.

(960015-1)

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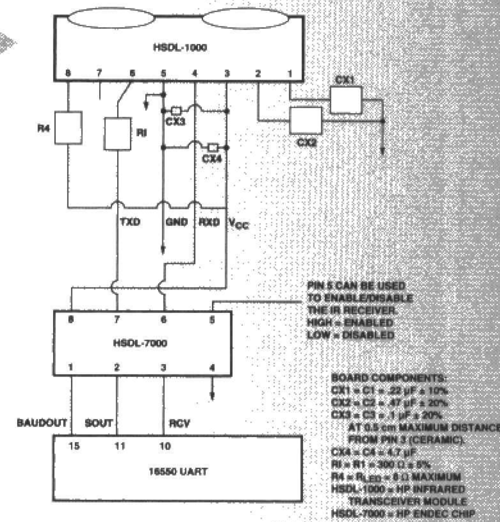

Fig. 9. A separate IR interface IC is necessary for the link between a UART and an IR module. Here, the HSDL-7000 is used.

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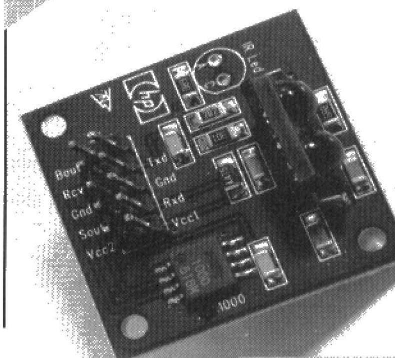

Fig. 10. Hewlett Packard's 'SIR' IrDA Evaluation board comes with the HSDL-1000 and HSDL-7000 installed.

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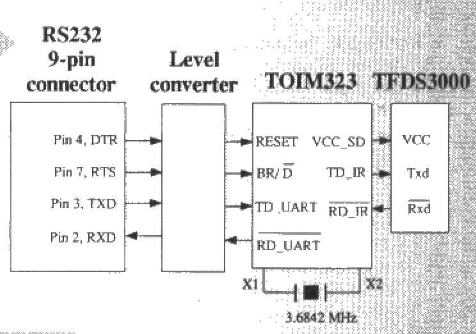
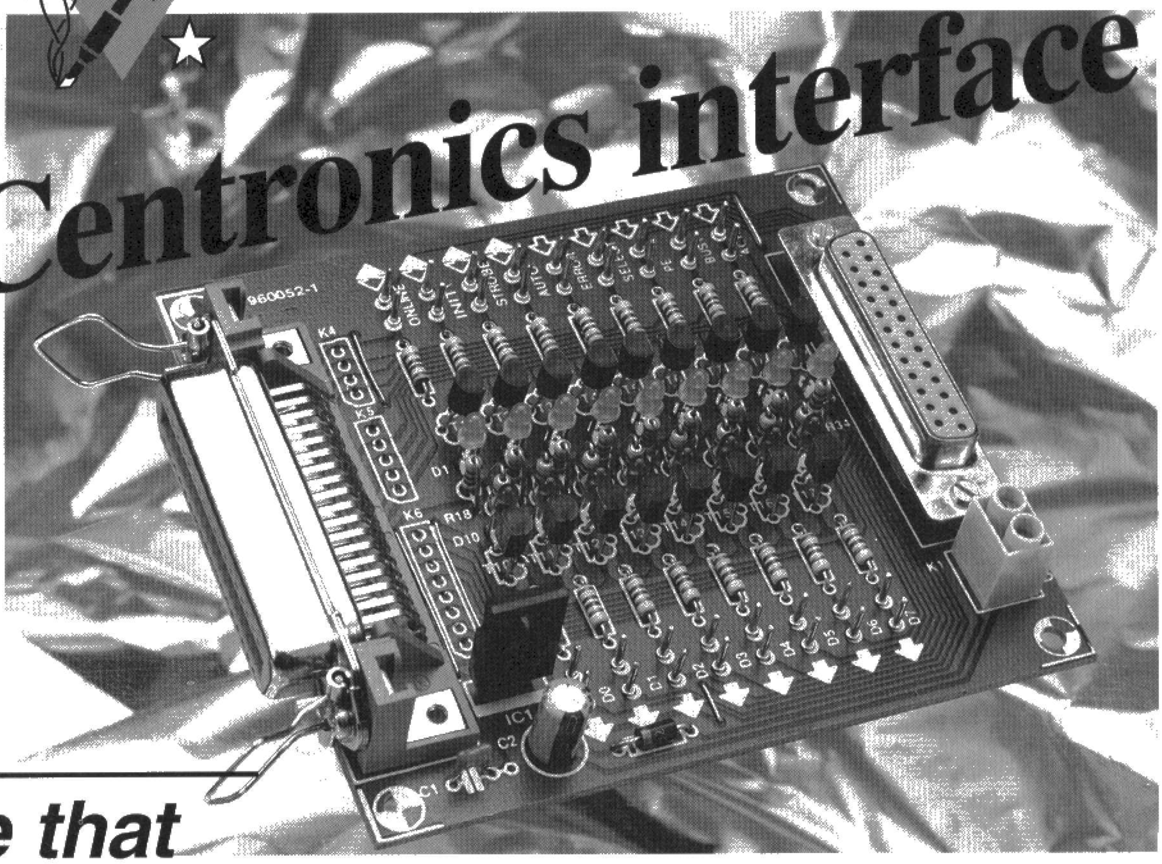


Fig. 11. Block diagram of an IrDA adaptor for RS232 interfaces.

Centronics interface



use that printer port!

Lots of people seem to think that computers show the results of their number crunching activities on screens only. The highly educational circuit described here demonstrates that a standard PC interface such as the parallel printer port may be used for applications which are off the beaten track. It may be used, for example, to drive external circuits. After your experiments, the circuit may be used as a permanently installed data exchange monitor in the PC-to-printer link.

Design by J. Feltes

Most, if not all, modern PCs feature a Centronics port to drive a printer with parallel data. It is possible to do more with that port, however. Just add a little hardware and software and you can turn it into a versatile controlling device for lots of external circuits.

The Centronics interface described in this article gives access to the control and data lines contained in the Centronics port. An array of LEDs (light-emitting diodes) provides a permanent indication of the logic levels on the various interface lines.

Let's start by examining the parallel printer port in some detail. It consists of three sections: an 8-bit output, a 5-bit input and a 4-bit bidirectional port. Bidirectional means that the latter four bits may be used as inputs or outputs, depending on how they are programmed. The eight outputs are designated D0 through D7. The five inputs are called Busy, Ack, Pe, Online and Error. The meanings of these descriptions are not discussed here because they are irrelevant to the present application. What we do explain, however, is how the printer port may be turned into a versatile digital control port with the aid of a couple of simple BASIC instructions.

Inside the PC

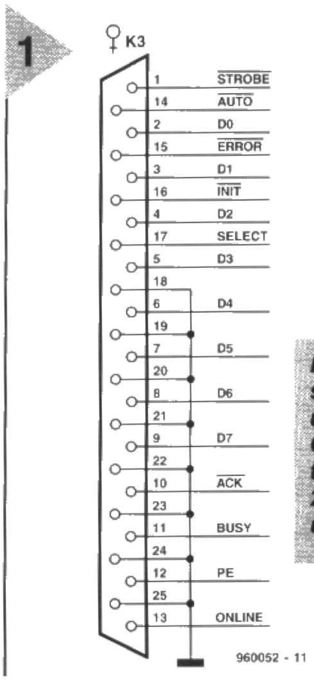
Practically every PC has a Centronics port, usually in the form of a 25-pin sub-D connector at the back of the case. The pin functions on this connector are shown in **figure 1**. Inside the PC, this connector is wired to a special integrated circuit which acts as an intermediate memory for output signals, and as a buffer for input signals. To the computer, this IC looks like an ordinary memory location where data can be read and written.

PCs recognize two types of address: 'ordinary' memory addresses and so-called 'input/output' (I/O) addresses. The Centronics IC is located in the I/O address range, and occupies three base addresses. The standard configuration in a PC allows up to three Centronics ports, LPT1, LPT2 and LPT3, to be defined. The respective base addresses reserved for these ports are 378_H, 278_H and $3BC_H$.

Practical circuit

The Centronics interface is a compact and straightforward circuit. Its structure is evident from **figure 2**. Each I/O line is fitted with its own on/off indicator consisting of an n-p-n transistor, two resistors and an LED. The LED lights as soon as a logic high level (2.4-5 V) exists on the line, irrespective of it being programmed to function as an input or an output. In other words, it is irrelevant whether the high level is generated by the computer or the peripheral device connected to the Centronics interface.

To make sure that the operation of the circuit remains simple and easy to observe, each of the three signal groups (inputs, outputs and bidirectional lines) has its own LED colour. Each of the eight outputs has a red LED, while the inputs have green LEDs. The four bidirectional lines are marked by yellow LEDs.



The inputs/outputs which may be used for experiments are always formed by two PCB pins. Their practical use is simple because the text printed near each pin pair indicates which I/O lines they are connected to. These pins may be used to connect TTL (transistor-transistor logic) compatible circuits, i.e., most logic circuits operating at a supply voltage of 5 V.

Because a relatively high current is required to make the LEDs light, the circuit is endowed with its own power supply. This supply consists of a voltage regulator (IC1, the ubiquitous 7805) and two decoupling capacitors (C1 and C2). Diode D18 acts as a polarity reversal protection.

Fig. 1. At the printer side, the printer cable usually has a 36-way Centronics plug. At the computer side, a 25-pin sub-D plug is used.

Construction

Building the circuit really should not cause any problems. If you make use of the ready-made printed circuit board supplied through our Readers Services (artwork shown in **figure 3**), it is all plain sailing – just follow the information in the parts list and the component references printed on the board.

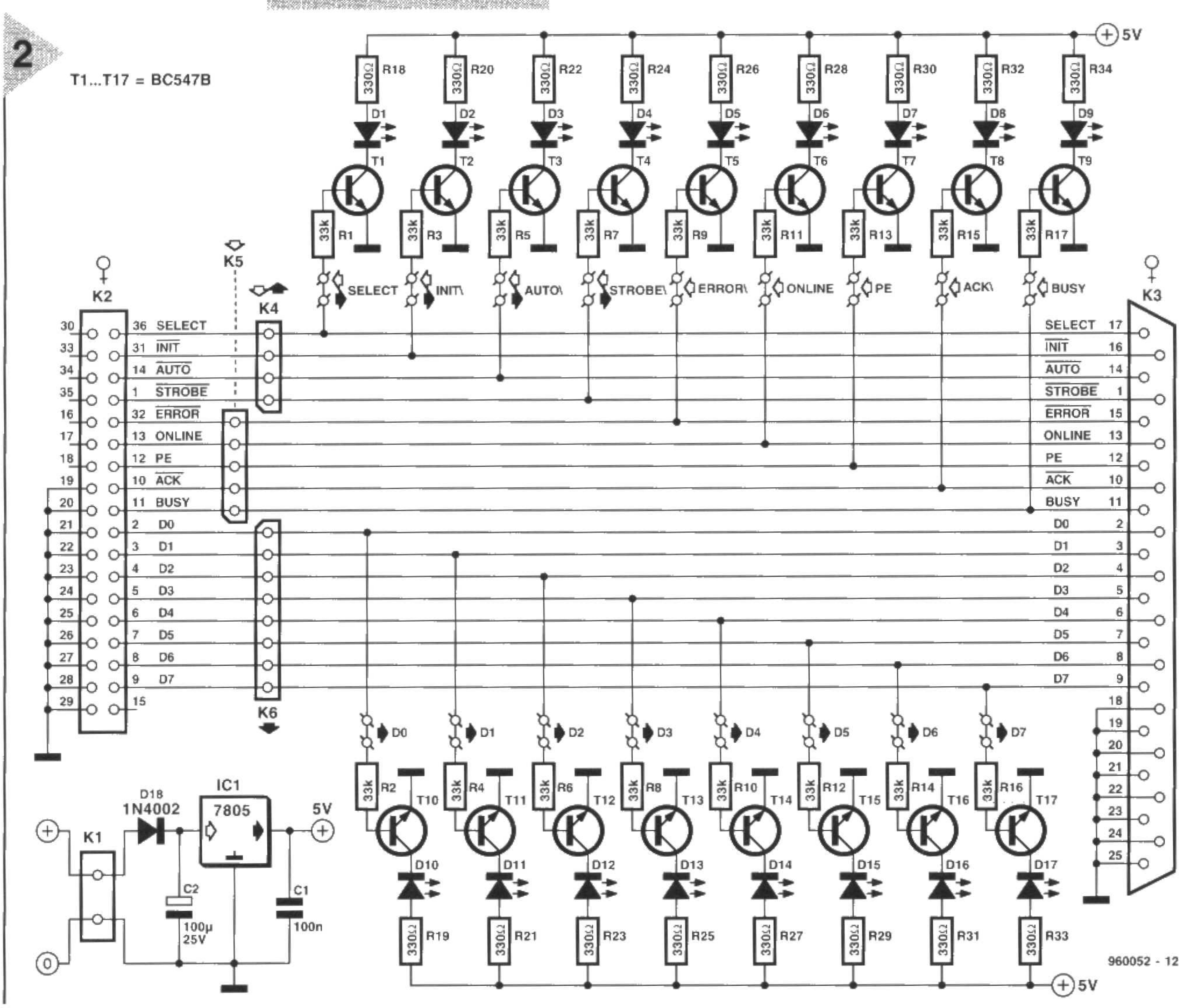
Fig. 2. The circuit is simple by almost any standard, consisting of no more than 17 transistor driver stages and a voltage regulator.

Start by fitting the five wire links, then fit the connectors. Socket K1 is a screw-type PCB terminal block, K2 is a PCB-mount Centronics socket, and K3 is a 25-way sub-D connector with straight solder pins, also for PCB mounting. Connectors K4, K5 and K6 are simple to make by cutting pieces of four, five and six pins from a 20-pin SIL pin header with 0.1-inch (2.54-mm) raster. Next, mount all capacitors, resistors, transistors and LEDs. The last two components are polarized, and care should be taken to mount them the right way around.

Give the completed circuit a thorough visual inspection to make sure there are no short-circuits or other mounting faults.

Testing and faultfinding

Provided the visual check does not reveal any errors, the circuit is ready for some practical testing. That is best done by inserting the interface into an existing link between a computer and a peripheral. Apart from the interface, you will need a 9-volt d.c. mains adapter and an extra printer cable for this test.



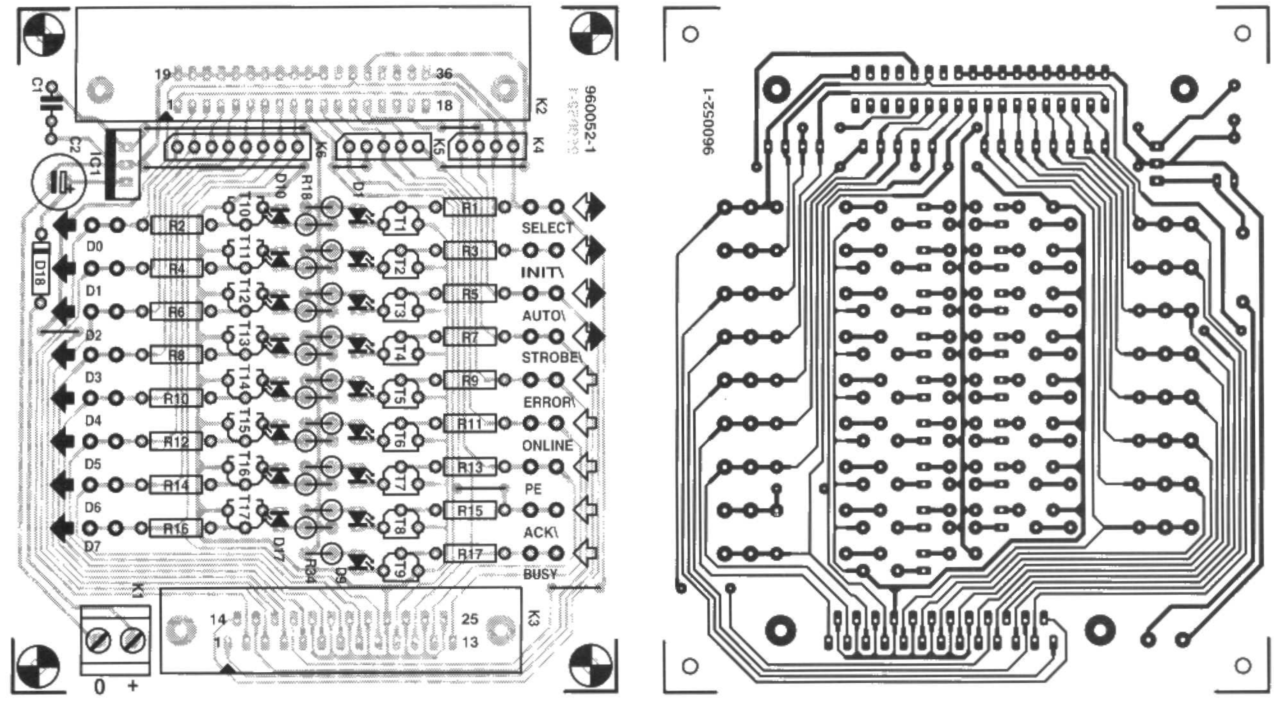


Fig. 3. Track layout and component mounting plan (90%) of the printed circuit board designed for the Centronics interface (board available ready-made, see page 70).

Disconnect the printer cable from the printer, and connect the cable end to the Centronics socket on the interface. Then connect the extra printer cable between the output of the Centronics interface and the input of the printer, as illustrated in **figure 4**. After this simple modification, it should be possible to use the printer as before. If so, you may connect the mains adapter to the circuit. The LEDs should flash if text or graphics are sent to the printer. If that happens, you may safely assume that the interface works properly.

In the unfortunate (and unlikely) case of the communication between the computer and the printer being interrupted after the circuit is inserted in the link, it is recommended to first check if the printer cables are all right and properly plugged into the sockets. Next, check that the solder work on connectors K_2 and K_3 is okay. If the cables are all right, the solder work is almost certainly the cause of the problem.

If the link between the computer and the printer appears to be intact, but the LEDs do not light, check the presence of the 5-V supply voltage (it can be measured across capacitor C_1). If the voltage is present, but the LEDs still do not light, you may have used the wrong transistors, or the LEDs may be fitted the wrong way around.

COMPONENTS LIST

Resistors:
R1-R17 = 33kΩ
R18-R34 = 330Ω

Capacitors:
C1 = 100nF
C2 = 100µF 25V radial

Semiconductors:
D1-D4 = LED, 3mm, yellow
D5-D9 = LED, 3mm, green
D10-D17 = LED, 3mm, red
D18 = 1N4002
T1-T17 = BC547B
IC1 = 7805

Miscellaneous:
K1 = 2-way PCB terminal block, raster 5mm
K2 = Centronics socket, angled pins, PCB mount
K3 = 25-way sub-D socket, straight, PCB mount
K4 = 4-pin SIL header
K5 = 5-pin SIL header
K6 = 8-pin SIl header
Printed circuit board and Windows software on diskette, order code: 960052-C (see page 70).
Diskette also available separately, order code 966008-1 (see page 70)

LET'S DO IT WITH BASIC

Once the interface is completed, the control of the LEDs may be tackled with the aid of BASIC. Actually, it is recommended to use the program 'QBASIC' which is supplied with any recent DOS.

Start by tracing the base address of the interface. Do this with the help of the computer. Change to the directory which contains the file QBASIC.EXE, and start this program by typing

```
QBASIC <enter>
```

Enter the program printed below. The number after 'LPT=' is the number of the printer port you wish to use. If you have only one printer port, the number will be '1' as shown in the listing. The operating system (DOS) stored the printer port addresses during its boot-up procedure. The BASIC program reads this data. The texts behind the apostrophes (') are comment only, and may be left out if you hate typing.

```
DEFINT A-Z
LPT=1                        'determine LPT address,
LPT=1, 2 or 3
DEF SEG = 0                  'select segment
A = &H408 + 2 * (LPT - 1)
                             'compute address
lsbaddr = PEEK(A)            'read 8 bits from memory
msbaddr = PEEK(A + 1)        'read 8 bits from memory
LPTaddress = lsbaddr + &H100 * msbaddr
                             'make 16 bit address
DEF SEG
PRINT HEX$(LPTaddress)        'print LPT address
                               in HEX on screen
END
```

Once the base address of the printer port is known, you also know the addresses of the 5-bit input port (base address+1) and that of the bidirectional port (base address+2).

BIT MANIPULATIONS

The Centronics port addresses are easily accessed from BASIC by making use of the instructions OUT (write to an address) and INP (read an address). When you use the instruction INP, the PC 'knows' that an address in the I/O range is meant, rather than an address in the 'regular' memory (which can be accessed with the PEEK and POKE instructions).

Using OUT or INP to access the base address of the Centronics port actually actuates the 8-bit output section. Increasing the base address by 1 gives access to the 5-bit input. The 4-bit bidirectional port, finally, is located at base

address plus 2.

The lines that make up the 5-bit input register are:

signal	bit
BUSY	7
ACK	6
PE	5
ONLINE	4
ERROR	3

The lines in the bidirectional register are:

signal	bit
SELECT	3
INIT	2
AUTO	1
STROBE	0

For example, if you want to make LED D_3 light, the following sequence should be followed. The instruction OUT &H378,8 causes a high level at bit 3 (D_3) of the 8-bit output (the value 8 equals 2^3, and that means bit 3 is selected). Similarly, the instruction INP (&H378) enables you to read the current status (level) of the 8 output lines contained in the Centronics printer port. The value which is read back is presented as a binary number that tells you which of the eight outputs is/are logic high. An example: suppose the value 12 is read. That equals 00001100 in binary notation. In other words, LEDs D_2 and D_3 light.

Reading the levels of the 5-bit input is simple, too, by programming INP (&H379). The value returned by the program is also written out in binary notation. The lower three bits are always zero because they are not used. The other bits indicate the levels of the inputs. Note, however, that the highest bit is always inverted before indication. So, a 0 at the highest (most-significant) bit position is indicated by 10000000 in the binary number returned by the register.

The 4-bit bidirectional port allows the INP as well as the OUT instruction to be used at base address+2. Here, too, it should be noted that bits 0, 1 and 3 are inverted. Before reading any data from these lines, make them 1 using the OUT instruction. **Note: the higher-order four bits at this address must never be made logic 1. If you do, the PC will crash.** Next, the logic levels on the lines may be read using the INP instruction.

An example showing you how to make the outputs do a running lights imitation is shown in the inset.

A Windows program

The author wrote a useful little program for the interface. This program runs under Windows 3.1 or Windows 95. You are presented with three small windows on the screen. Each of these windows shows the settings of all lines in one of the Centronics port sections, in binary as well as decimal notations. You may set levels yourself by clicking on buttons. The program is very user-friendly, and may be obtained on diskette through our Readers Services (see page 70). (960052)

RUNNING LIGHT IN SOFTWARE

Once the interface has passed the test for correct operation, you may program a running light using the LEDs connected to the eight output lines. A program which performs this function is listed below.

The loop is repeated until the user presses the escape (Esc) key on the keyboard. The example is based on the assumption that the printer port at address 378_H is used. If a different address is used, the relevant value must be entered. The program writes all 0's to the port, except for one bit. The LED which belongs to this bit lights, while all others remain out. Note that you automatically arrive in a different window when you start typing the subroutine. Function key F2 allows you to change between the main program and the subroutine.

```
DEFINT A-Z
DO
 FOR i = 0 TO 7                'drive all 8 LEDs
   a=2^i                       'a trick to make one bit high
   OUT&H378,a                  'write to port
   Waitloop 5000               'wait a while
 NEXT i                        'next LED
LOOP UNTIL INKEY$=chr$(27) 'start over unless Esc pressed
SUB Waitloop (count)           'this is the wait subroutine
 FOR I = 1 to count            'do this empty loop
 NEXT I
END SUB                        'done, return to main program
```

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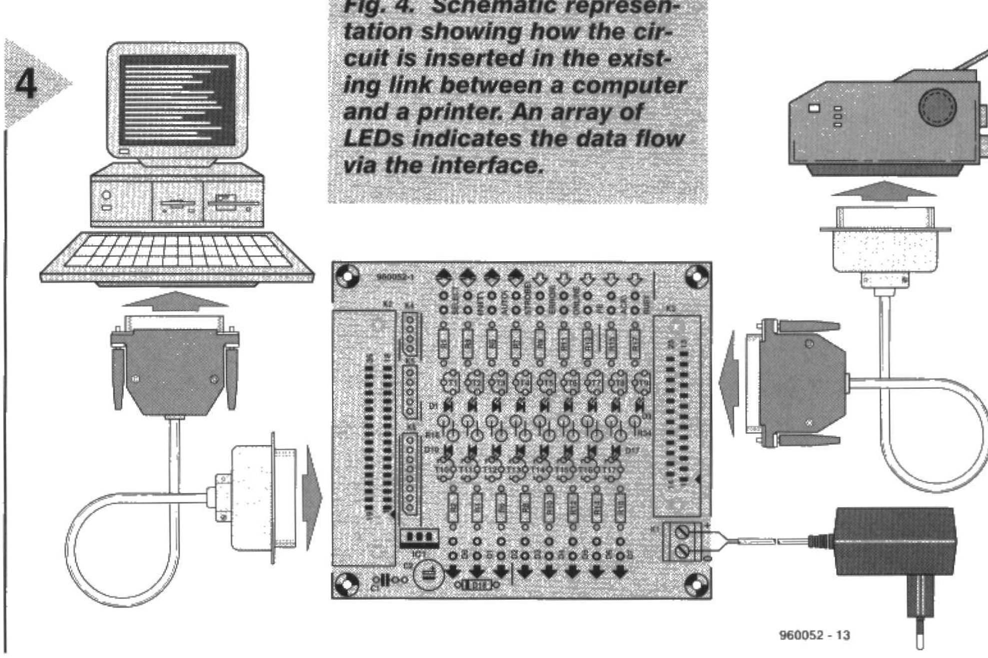

Fig. 4. Schematic representation showing how the circuit is inserted in the existing link between a computer and a printer. An array of LEDs indicates the data flow via the interface.

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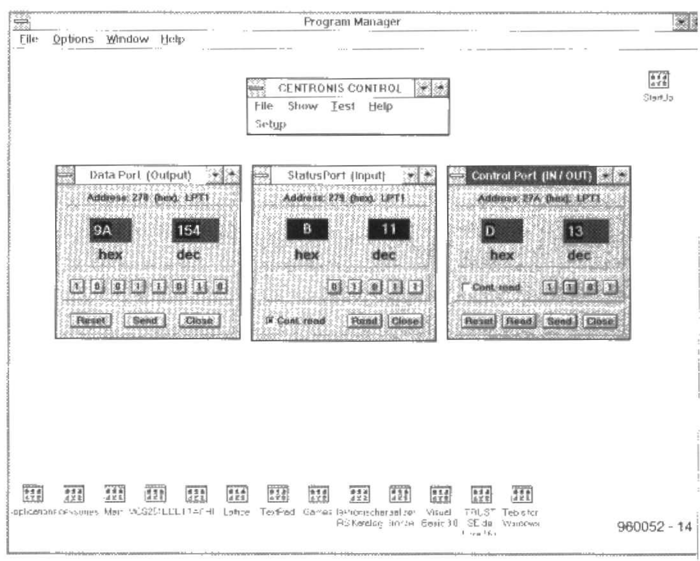


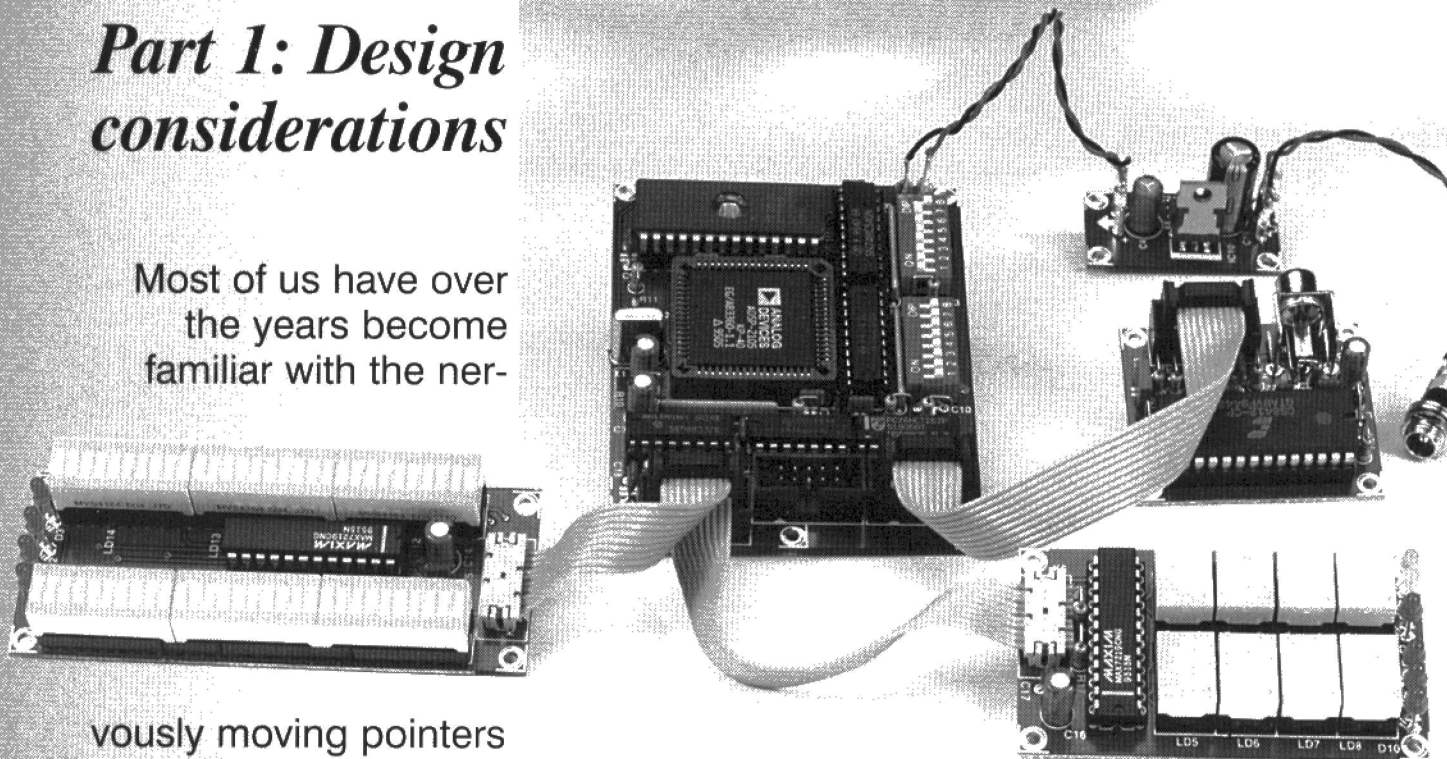
Fig. 5. This Windows program clearly indicates the logic levels carried by the Centronics interface. Mouse-operated push-buttons allow you to change the logic levels.

digital VU meter

Part 1: Design considerations

Most of us have over the years become familiar with the nervously moving pointers or LED bars of the VU (visual unit) meter on the front panel of a cassette tape recorder or mixing panel that indicate the level of the a.f. signal. The circuit presented in this two-part article is a variant of this meter that can be inserted directly in series with the a.f. signal line. Its specifications are reminiscent of professional equipment. We are not entirely certain, but think that this is the first DIY VU meter ever published in a magazine.

Design by T. Giesberts



for direct measurements of digital audio signals

The introduction of digital audio (CD, DCC, DAT, MiniDisc) in the 1980s has drastically changed the world of audio and hi-fi. Many analogue circuits have been replaced by black boxes like digital filters and signal processors. The a.f. data has been changed from a series of waveforms to a train of binary digits (bits).

Brief technical data

Display	double alphanumeric 3 1/2-digit
	double 30-segment led bar with peak indication
Brightness	individually presettable
Measuring range	138.5 dB (with 24-bit input)
Resolution	0.1 dB (±0.005 dB)
Input	S/PDIF 16–24 bit; i2s 16–24 bit
Sampling frequencies	32 kHz, 44.1 kHz, 48 kHz
Measurement	peak, PPM, and RMS
Status indication	by 10 LEDs on front panel

The present VU meter is geared to the new technology. Where in earlier times a net-

** Sony/Philips Digital Interface Format – the consumer version of the AES/EBU standard. This standard was devised by the American Audio Engineering Society (AES) and the European Broadcasting Union (EBU) to define the signal format, electrical characteristics and connectors to be used for digital interfaces between professional audio products.*

work consisting of a capacitor, a resistor, a diode and a mini moving-coil meter was used for level indication, in modern equipment this network is replaced by a digital signal processor—DSP. This results in a rather more compact instrument that gives excellent performance.

The VU meter is based on a Type 2105 DSP from Analog Devices. This 16-bit device is designed and programmed to enable data to be processed with a 64-bit resolution. This means that 24-bit wide data are processed with an arithmetical error that, in the end result, is smaller than 0.025 per cent. The arithmetic is carried out fast and accurately. The speed of it is provided by an integral multiply accumulator (MAC). For example,the multiplication of two 16-bit numbers which must be retrieved from the memory and the adding of the result to an existing number or storage into a memory location takes rather less than 100 ns.

Since the VU meter is intended for measuring digital a.f. signals, it itself is designed on digital lines.

Also, the processing is controlled by software wherever possible, which obviates the use of special components (to keep any errors down). This arrangement also keeps the cost down and results in a compact, flexible meter.

MEASURING: WHAT AND HOW

The basic design of the meter is shown in the block diagram in **Figure 1**. A large part of the meter is taken up by the displays. Apart from the two 30-LED bars, there are also two 3½-digit-wide alphanumeric displays. Both display groups are controlled by a dedicated controller from Maxim, the Type MAX7219.

The LED bars give a a good visual indication of the signal level: they simulate the moving pointer of VU meters of yesteryear.

The alphanumeric display shows the peak level measured during a recording session.

There are also several LEDS that indicate which functions of the meter have been selected.

The input of the meter is formed by an S/PDIF* receiver connected to a multiplexer. Several inputs of the multiplexer are (as yet) unused, but are intended for connecting an analogue-to-digital (A/D) converter which we hope to publish in a future issue.

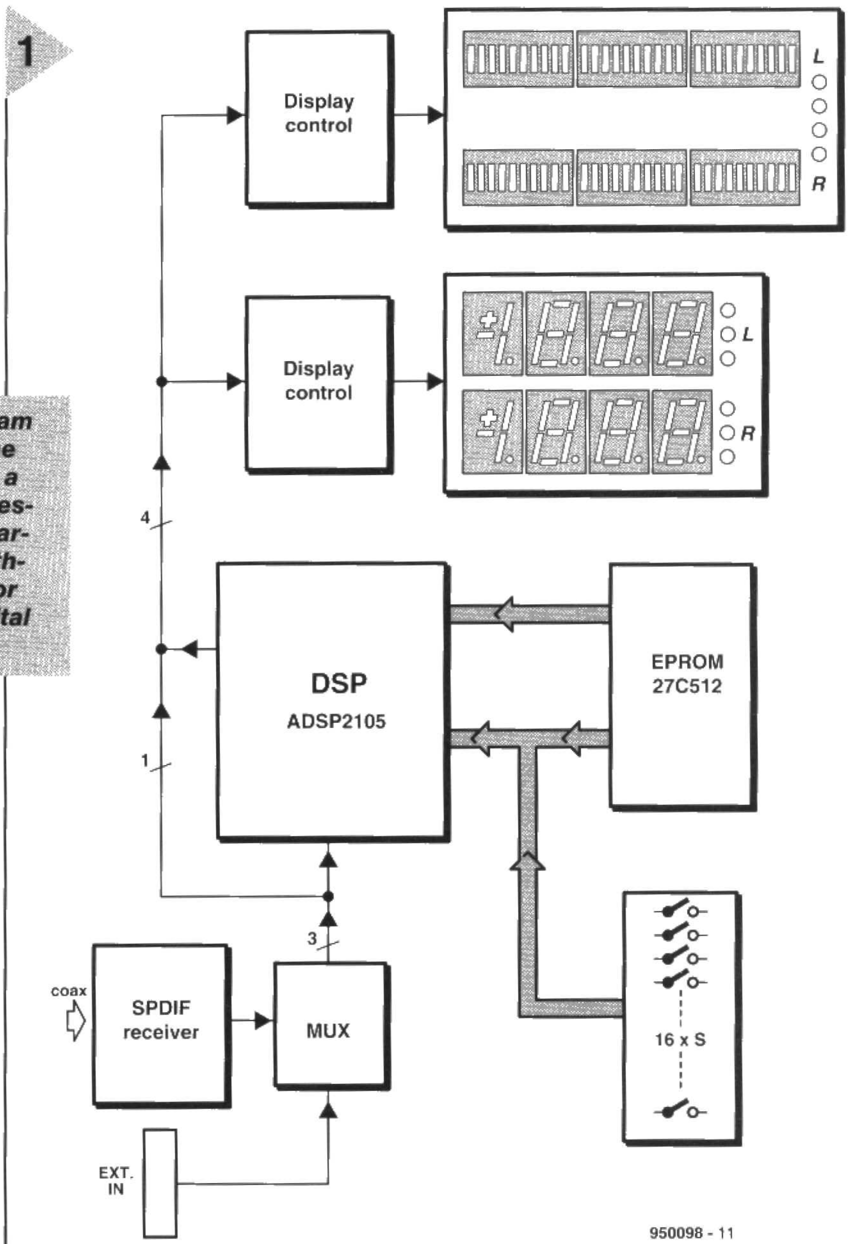


Fig. 1. Block diagram of the VU meter. The meter is based on a digital signal processor—DSP—which carries out all the arithmetic necessary for displaying the digital a.f. level.

Table 1. Positions of dip switches

1.1	peak hold time	hold/update (1.95 s)
1.2	spot hold time	hold/update (1.3 s)
1.3	spot mode	peak/PPM
1.4	led bar mode	peak/PPM
1.5	mode	RMS/PPM or peak
1.6	scale	dBu/dBfs
1.7	0 dB ref. left	set
1.8	0 dB ref right	set
2.1	B0 current led bar	1/0
2.2	B1 current led bar	1/0
2.3	B2 current led bar	1/0
2.4	M0 current margin display	1/0
2.5	M1 current margin display	1/0
2.6	M2 current margin display	1/0
2.7	Input selection	S/PDIF/i2s
2.8	not used	

The output signals of the multiplexer are applied to the digital signal processor. Note, by the way, that this DSP has been used in an earlier article in this magazine.

Since a DSP is designed for a specific application, that is, the fast processing of digitized analogue signals, it needs software to perform as needed. The software is stored in a Type 27512 EPROM. The RAM required by the dsp to work properly is integral: thus, there is no external ram.

The writing of the state of the dip switches is enabled by the addition of a 16-bit wide input gate.

The various modes and functions of the meter are selected with a switch on the front panel and some DIP switches on the board. They are summarized in **Table 1**. Note that they can be selected semi-permanently with the dip switches, because it is assumed that modes and functions are chosen only once. If more flexibility is required, for instance, if the meter is to be used as a laboratory measuring instrument, the DIP switches can be replaced by standard switches on the front panel.

Circuit description

The complete circuit of the VU meter is shown in the diagram in **Fig. 2**. It may be split into five parts: the processor, the S/PDIF receiver, the LED bars, the alphanumeric display and the power supply.

The power supply is a straightforward regulated design. Since digital signals are processed at high switching speeds, the supply decoupling has been given more than usual attention. This has resulted in a number of ICs being provided with their own decoupling capacitor.

The S/PDIF, a Type CS8412 from Crystal (IC_{11}), has no

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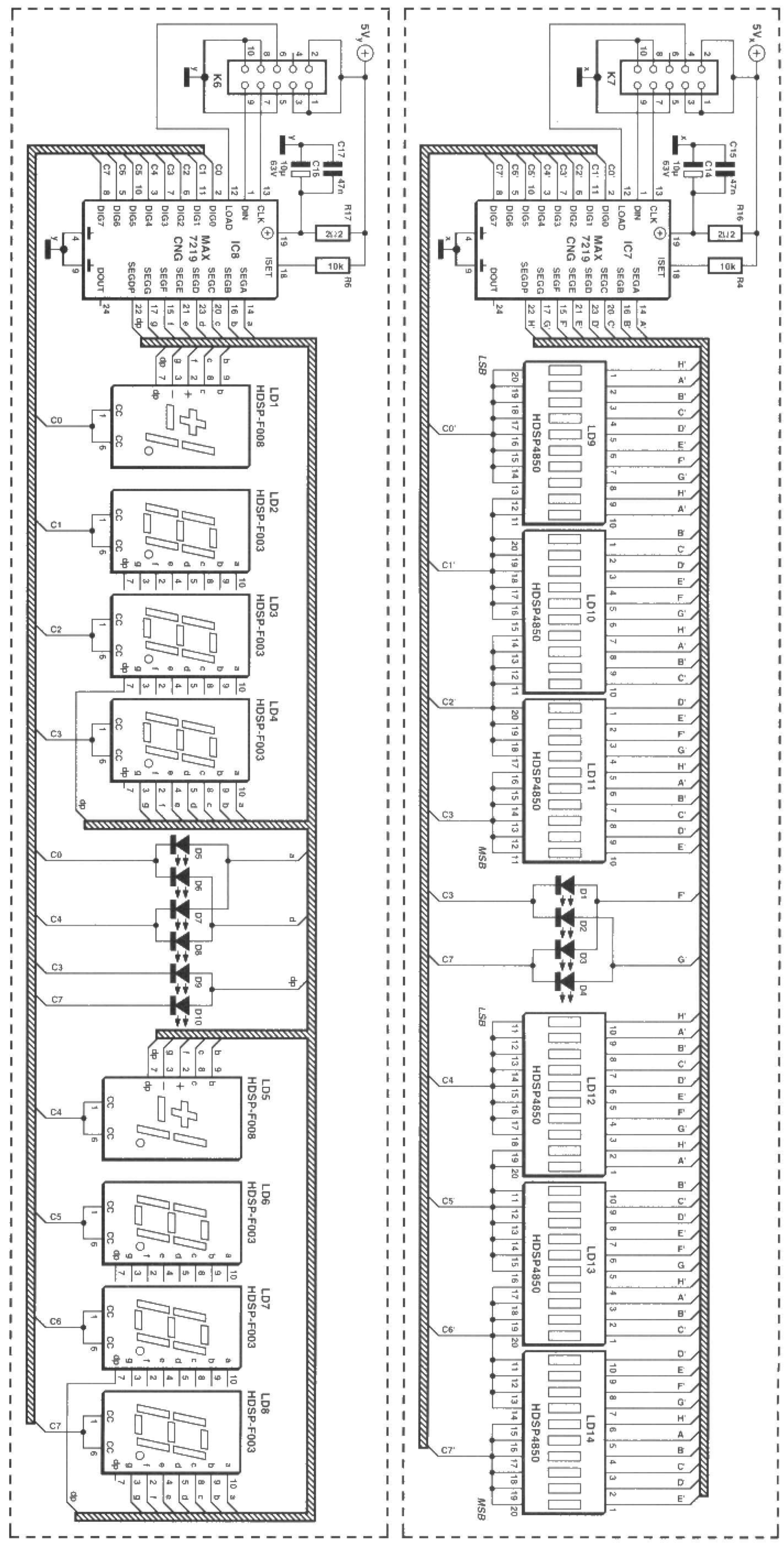
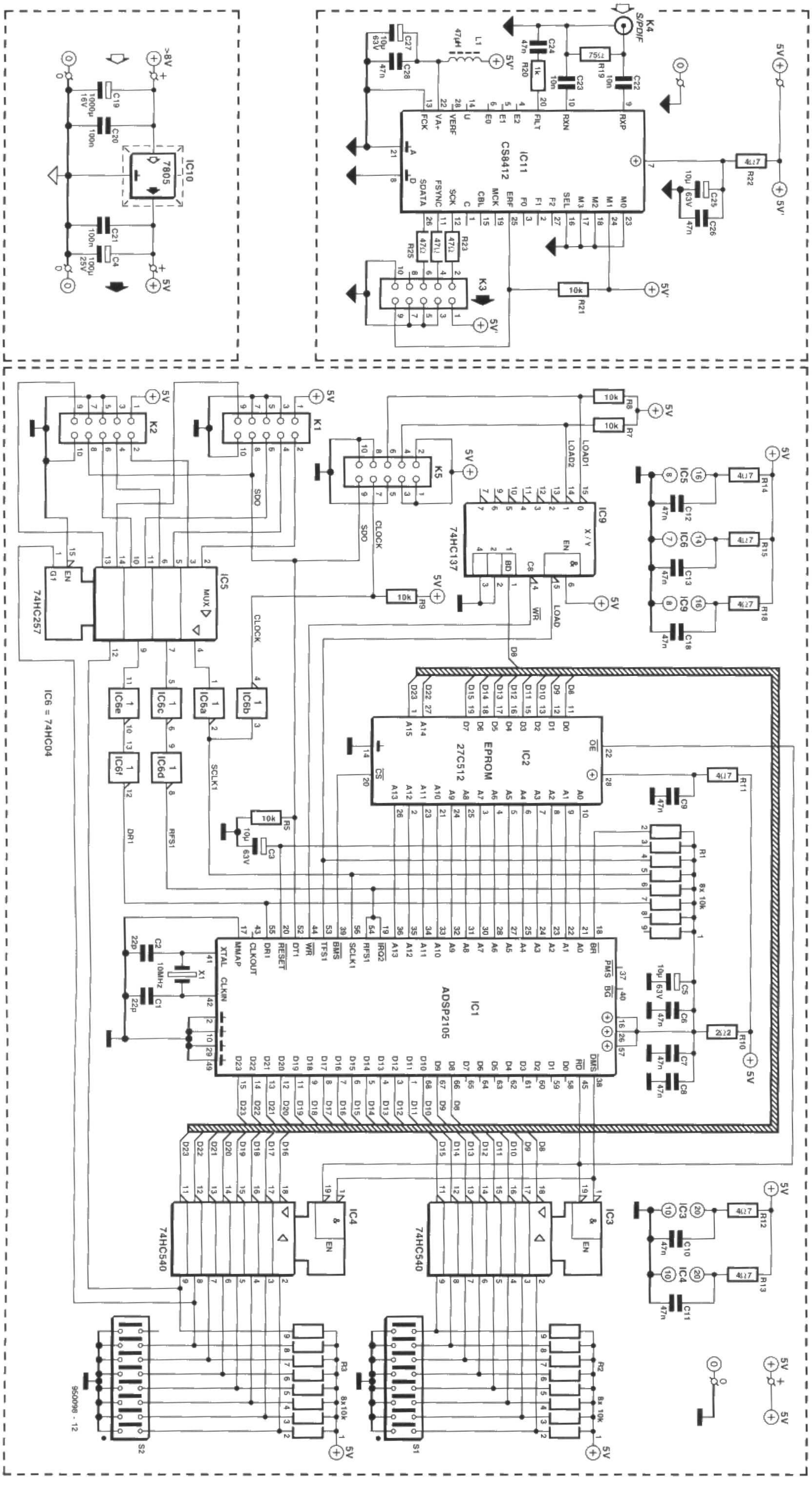


Fig. 2. The use of intelligent components keeps the circuit fairly small. Most of it consists of LEDs, displays and associated drivers.



surprises: it offers a good and ready integrated solution to the design requirement. It is discussed in more detail in the box on page 39. Note, however, that it has only a coaxial input; optical signals must be connected via an optical receiver, such as the TORX173 from Toshiba.

The digital a.f. data produced by the interface is output via K_3. This connector is linked to K_1 on the mother board via a short length of flatcable. Connectors K_1 and K_2 are arranged in an identical manner; K_2 is intended for a future extension, such as a modern analogue-to-digital converter—ADC.

The signals at K_1 are applied to the DSP, IC_1, via multiplexer IC_5.

The clock retrieved from the digital data is applied to the SLCK1 input. In this way, the digital signal determines the digital serial clock frequency.

The serial a.f. data derived from the S/PDIF signal are applied to input DR1.

Finally, the synchronization signal contained in the S/PDIF data is applied to input RFS1.

The circuits on the display boards operate in like manner. Display controllers IC_7 and IC_8, both Type 7219 from Maxim, communicate serially with the mother board. This data link uses signals Load, Clk and Data. To give the user maximum freedom in the building of the meter, the displays are linked to the mother board via a short length of flatcable (K_5–K_7).

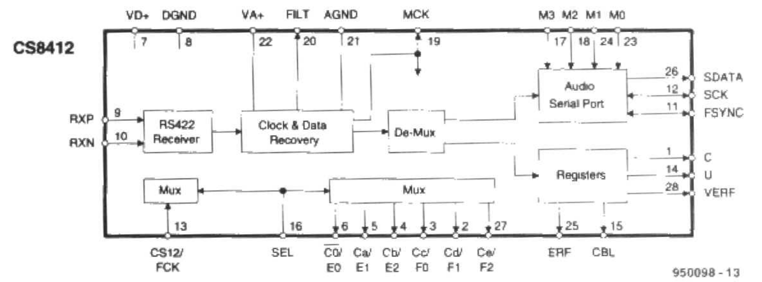
Connectors K_5–K_7 also carry the supply lines (+5 V and earth).

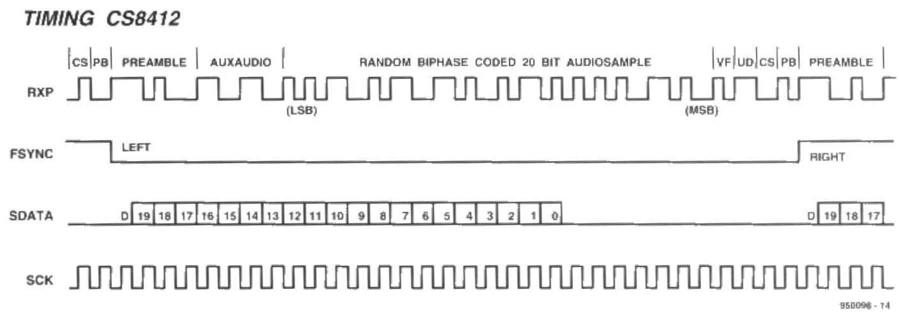
The brightness of the displays may be

S/PDIF signal decoder

Decoding digital a.f. signals is fairly straightforward with the use of a special ic, here the Type CS8412 from Crystal Semiconductor Corporation. It is a monolithic CMOS device that receives and decodes a.f. data according to the AES/EBU, IEC958, S/PDIF and EIAJ CP-340 interfaces standards. It receives the data from a transmission line, recovers the clock and synchronization signals, and demultiplexes the a.f. and digital data. The timing diagram shows how this is done.

The chip can accommodate ×256 oversampling since the clock is 256 times the sampling frequency.





altered as required by changing the values of resistors R_4 and R_6. Which of the displays is accessed depends on the level of the Load line. The Load signal is generated by the DSP and split into Load1 and Load2 by multiplexer IC_9.

After the LED controller has written a complete data word, it begins to control the display. One controller can control 64 LEDS or eight 7-segment displays. Since the present meter uses 3½-digit displays, some capacity is left to control LEDS from the display. The needed multiplex signals are generated by the display controller.

Writing the state of the DIP switches is effected by IC_3 and IC_4, both Type 74HC540 devices, which are used as 16-bit input. Since this gate is the only I/O hardware available to the DSP, the DMS (Data Memory Select) line can be used to select either of the ICS. The state of all switches is written in one go. The gate is linked to data lines D_8–D_{23}.

The system software is stored in IC_2. This EPROM is enabled by the BMS (Boot Memory Select) signal. It will be noted that only eight data lines are used, whereas internally a 24-bit wide bus is provided. Analog Devices has chosen a system whereby in the EPROM three bytes are sequential, which in the DSP are placed in parallel again. A slight disadvantage of this arrangement is that writing the boot software takes just a little longer. The benefit is, however, that the circuit is simpler and cheaper.

VARIOUS POSSIBILITIES

The VU meter is a flexible instrument: the desired function may be selected with DIP switches. A summary of these possibilities follows.

One LED of the LED bar is used to retain the peak level. The function of the peak indicator is set to hold or update with DIP switch 1.2. In the update mode, the measured value is adapted every 1.3 seconds.

Both the LED bar and the spot measurement may operate as required in the Peak Program Meter (PPM) mode or the Peak mode. The PPM mode is a standard used for the registration of the average a.f. level. This standard also specifies the attack and decay times. All this means that in practice the LED bar reacts very rapidly to the applied a.f. signal.

DIP switch 1.6 enables either of two scale units to be selected: dBfs (decibel full scale) or dBu, which is an analogue reference, in which 0 dB corresponds to 775 mV, that is, 1 mW into 600 Ω. This scale is intended for measurements of digital signals where the 0 dB level is determined by the largest figure that can be generated by a given number of digits. An externally connected A/D converter is usually set so that full-scale deflection occurs at a level of +12 dBu.

The 3½-digit display shows the peak value in dB, just as the spot of the LED bar. However, it shows the level in figures with an accuracy of 0.5 per cent (0.1 dB). To improve legibility, 'hold' or 'update' may be selected with DIP switch 1.1. In the update mode, the measured value is updated every 1.95 second.

The r.m.s. mode is selected with DIP switch 1.5. Once selected, this mode applies to both the LED bar and the alphanumeric display.

The standard with r.m.s. measurements is the 0 dB full scale. In the present meter, this can be set manually for either the left-hand or right-hand channel. This arrangement allows a dB measurement to be carried out from any random signal level.

Calibration is straightforward: apply a test signal to the input and briefly close left-hand r.m.s. switch 1.7 and right-hand r.m.s. switch 1.8. This sets the 0 dB reference to the level of the applied test signal.

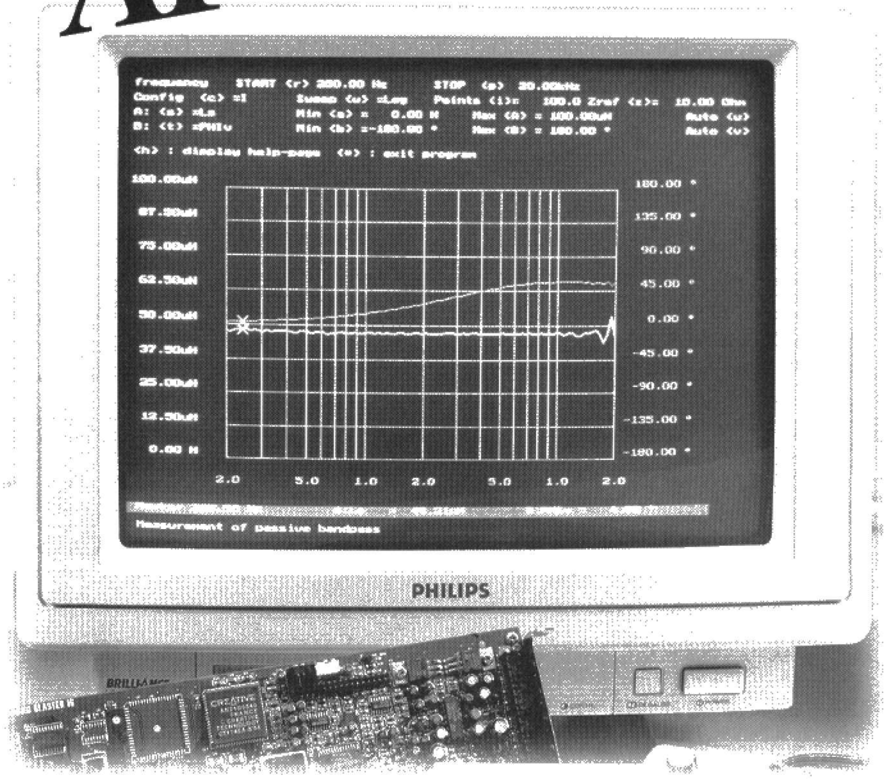
Finally, an important aspect is setting the brightness of the display. The brightnesses of the LED bars and alphanumeric display can be set independently of each other: DIP switches 2.1–2.3 are for the LED bars and DIP switches 2.4–2.6 are for the alphanumeric displays. This arrangement makes it possible for the brightness to be adapted to the ambient brightness.

Apart from by these digital settings, the setting current, I_{set}, can be altered by changing the values of reference resistors R_4 and R_6.

This ends the discussion on the design and setting of the VU meter. Next month the practical aspects and application of the meter in an existing system will be discussed.

(950098-1)

PC soundcard as AF analyser



After last month's introductory instalment on the main features of the AF analyser system, which consists of a PC soundcard and some dedicated software, this second and final instalment tackles more practical matters like suggestions for suitable measurement configurations, along with their peculiarities. The measurements make use of a small adaptor box which allows the measurement range and configuration to be set with ease. The box also offers various sockets for connecting components whose value is to be measured.

Part 2: Measuring loudspeaker parameters and amplifier frequency response curves

By Dr M. Ohsmann

To enable two-pole electronic components like resistors, inductors, capacitors and loudspeakers to be measured, the impedance measurement is actually performed as a gain measurement. The unknown impedance, Z_x, is connected to a precision resistor R_{ref} so that a voltage divider is created. As shown in **figure 1**, that can be done in two ways. By adapting R_{ref} to the measurement in question, the AF analyser software is capable of doing measurements in either configuration. To enable all this to be done in a comfortable manner, a measurement box with internal components as shown in **figure 2** is used. The measurement range and the configuration are readily set by means of switches. The software is, of course, informed about the relevant configuration and the measurement resistance. The wires to the measured object should be kept as short as possible to keep parasitics down to the lowest possible level. The length of the connecting cable to the Soundblaster card should not exceed 1 m.

1

Fig. 1. Impedance measurement is reduced to a four-pole measurement using a voltage divider.

Measurement options

With impedance measurements, the software distills the unknown impedance Z_x from the computed attenuation and phase of the voltage divider. The basic equations for the impedance calculation are inset in figure 1. The measurement software allows the user to select between a large number of display options, so that the desired measurement result is obtained in the easiest way. The screen allows two curves to be shown simultaneously. For example, if you want to check out an inductor in a loudspeaker cross-over filter, the component may be thought of as consisting of an ideal (loss-free) inductor **Ls** in series with a loss resistance **Rs**. Next, you select **Ls** (series inductance) and **Rs** (series resistor), and so obtain a frequency-dependent graph of the desired parameters. Because a real loudspeaker has capacitive and inductive components, you may want to select the real and the imaginary part of the impedance for the display (display functions **R** and **X**), or the phase of the impedance (display options **rz** and **PHIz**).

The equivalent circuits for the impedances with their references are shown in **figure 3**. All indicated replacement values may be displayed by the measurement software. The values that can be displayed for four-poles are also indicated.

Range selection

As with nearly every instrument, the measurement range should be matched to the object to be measured. Consequently, the measurement range is determined by the frequency and the reference resistance. The impedances to be measured cover several orders of magnitude in the audio range. For your reference, **figure 4** shows the impedance values of inductors and capacitors in the audio range. This graph may be used to decide on the measurement configuration and the value of the reference resistor. For results that make sense, the voltage divider should exhibit an attenuation in excess of 3 dB and smaller than 50 dB in the frequency range to be displayed. Similarly, to capture the imaginary parts reliably, the phase shift should be larger than 3 degrees.

Small impedances are always measured with the configuration marked I. The value of R_{ref} is then selected such that it is larger than the impedance to be measured. High impedances are measured using configuration II, in which R_{ref} is smaller than Z_x. If not even the order of magnitude of the impedance is known, the **V** and **PHIv** graphs should be used to make sure the above mentioned conditions as regards attenuation and phase of the voltage divider are satisfied.

At this point you are ready to measure unknown inductors and capacitors from the junkbox. Don't be surprised to see the series resistance of coils with an iron core rise sharply above 1 kHz or so | s you are looking at eddy and flux reversal losses! High-voltage electrolytic capacitors, too, may reveal appreciable series resistance.

Those small inductors and capacitors

Normally, you will be using inductors in the micro-henry and milli-henry range, and capacitors in the pico-farad and micro-farad range. The value of ex-equipment adjustable capacitors and inductors is rarely printed on the devices. The present AF analyser system allows the values of such (RF) parts to be measured with a fair degree of accuracy, provided you avoid the pitfalls of measurement errors. **Figure 5** shows how parasitic components may cause such errors with impedance measurements (for configuration I). The resistance (of up to 0.2 Ω) formed by the generator cable is marked R_G. Effectively, it is connected in series with the measured impedance Z_x. R_G

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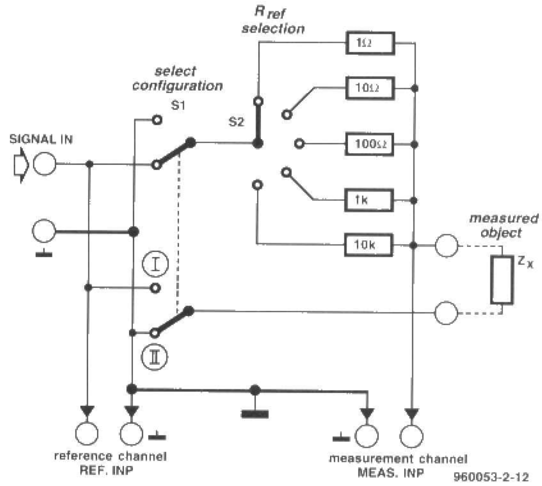

Fig. 2. This measurement box makes impedance measurements on various components a piece of cake.

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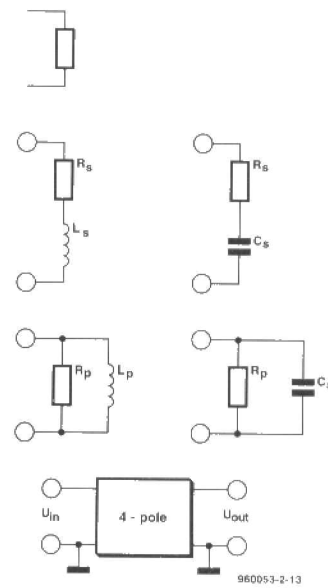

Fig. 3. Equivalent circuits and their parameters.

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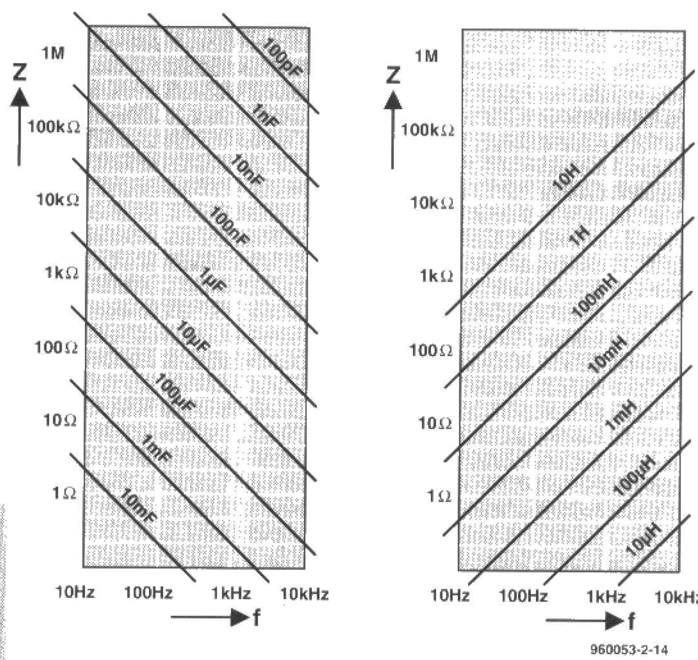

Fig. 4. Reference graphs showing inductor and capacitor impedances in the audio range.

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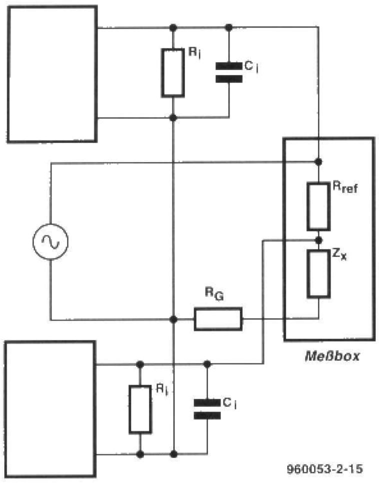

Fig. 5. Circuit of the measurement system with its inherent parasitic (stray) components.

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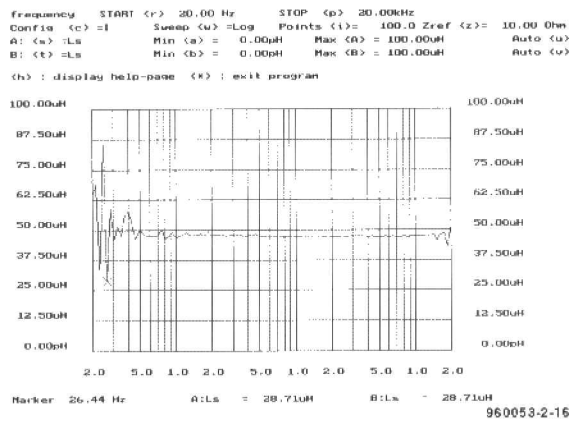

Fig. 6. Inductance measurement on a 47-µH choke.

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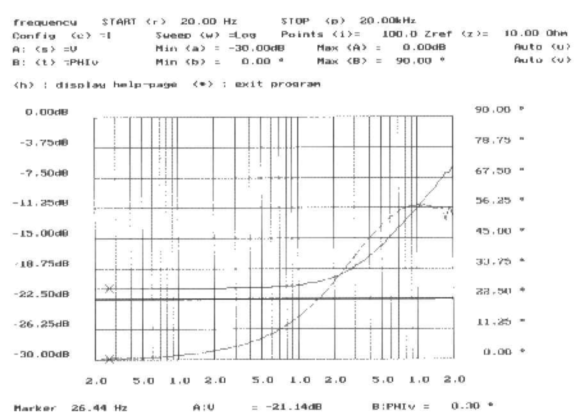

Fig. 7. Checking the attenuation and phase of the 47-µH choke.

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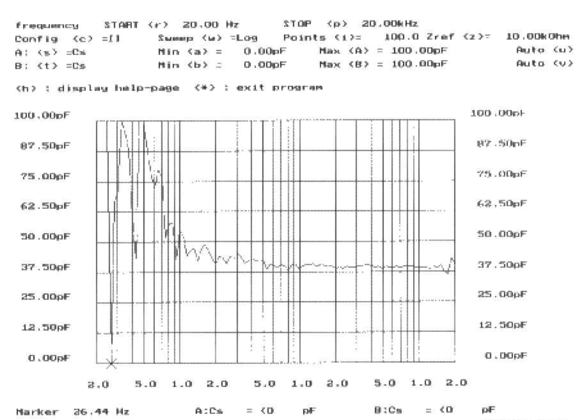
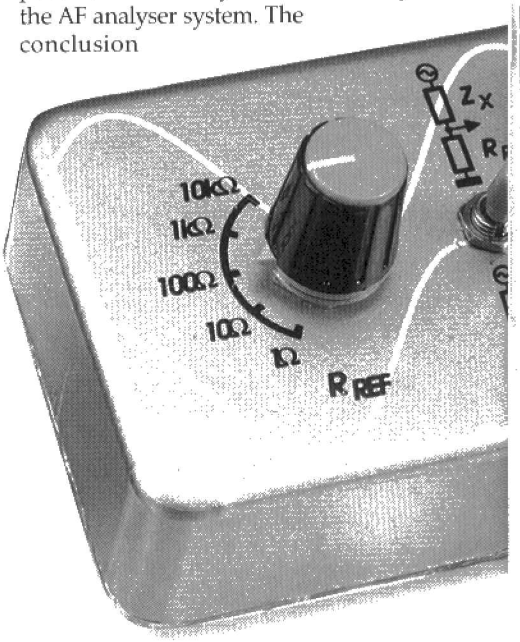


Fig. 8. Capacitance measurement on a 100-pF capacitor.

should be taken into account when measuring low impedances, and may only be neglected with rather high impedances. The measurement error caused by R_G is smallest at relatively high measuring frequencies, because the imaginary resistance is then large relative to the cable resistance.

The parameter marked R_i represents the internal resistance of the ADC (input amplifier), while C_i stands for the input capacitance. These two impedances are in parallel with Z_x, and interfere with measurements on high impedances, for example, small capacitances. You should, therefore, resort to configuration II. The internal resistance is a few hundred kΩ, and the internal capacitance, a few hundred pF.

Here are two examples of the effects caused by the parasitic inductance and capacitance. The reference graph indicates that a 100-µH inductor presents an impedance smaller than 1 Ω to signals below 1 kHz. This impedance can hardly be measured by the AF analyser system. The conclusion



is that higher frequencies should be used for measurements on small inductances.

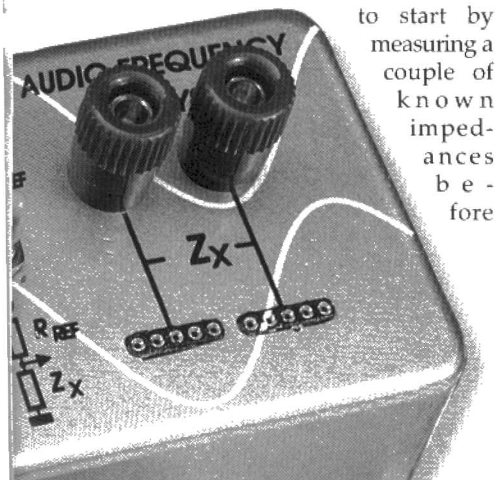
Figure 6 illustrates an **Ls** measurement (i.e., inductance in the equivalent circuit) on a 47-µH choke over the frequency range 20 Hz to 20 kHz. Obviously, the results in the range up to 200 Hz are totally wrong (as expected), simply because the impedance is then too small. As a check, use the **V** and **PHIv** graphs (**figure** 7), which provide information on the attenuation and phase of the voltage divider. Here, you get confirmation of the claim that meaningful impedance measurements are only possible at phase shifts greater than 3 degrees. The attenuation of between –4 dB and –22 dB seems to be all right at all test frequencies because the ohmic resistance is high enough to be measured with confidence at low frequencies, too.

Small capacitances of about 100 pF represent impedances larger than 1 MΩ to signals with a frequency below 1 kHz or so. Consequently, you must use configuration II, a frequency greater than 1 kHz, and a high reference resistance (of 10 kΩ) for the measurement. If you measure across the full frequency range of 20 Hz to 20 kHz, the result is a 'dodgy' curve (**figure 8**) below about 200 Hz because the impedance measurement does not make sense there. From about 1 kHz, however, a fairly accurate measurement is possible. The measured value

of the capacitor under test is about 40 pF, by the way.

Practice does it

As customary with the operation of complex measuring equipment, experience is only acquired after a good deal of experimenting, practicing and getting used to the instrument. It is recommended to start by measuring a couple of known impedances before



you venture out into the unknown. This little exercise prevents erroneous measurements and misinterpretation of measured results later.

Finally, a few remarks about the software and its options. The colours available for displaying curves, values and grids on the PC monitor may be defined in the file called AFA.PAR (see inset box). The complete set of measurement definitions performed by AFA.EXE is also contained in this file, and loaded when the program is started. It should be noted that the program makes (software) changes to the mixer on the Soundblaster card. Online help is available, offering explanations of the main functions of the program. The curves on the screen may be sent to the printer by pressing Print-Screen. It is also possible to combine several measurements in one diagram.

960063-2

Measurement options

Symbol	Reference		Meaning
	in AFA.EXE	in AFA.PAR	
R	R	2	real part of impedance
X	X	3	imaginary part of impedance
r_z	rz	10	value of impedance
φ_z	PHIz	11	phase of impedance
R_s	Rs	4	series resistance in series eq. circuit
C_s	Cs	5	series capacitance in series eq. circuit
L_s	Ls	6	series inductance in series eq. circuit
R_p	Rp	7	series resistance in parallel eq. circuit
C_p	Cp	8	series capacitance in parallel eq. circuit
L_p	Lp	9	series inductance in parallel eq. circuit
A	A	12	real part of complex gain
B	B	13	imaginary part of complex gain
V	V	0	value of complex gain
φ_V	PHIv	1	phase of complex gain

Project Software

The software for the AF analyser system is now available on diskette through our Readers Services. Price and ordering details may be found on page 60.

Configuration file AFA.PAR

The configuration file contains the measurement parameters as well as the display settings. The measurement parameters are set in the program AFA.EXE, and they are automatically copied to and read from the configuration file. By contrast, changes to the screen settings must be entered directly into the configuration file. The relevant parts are shown in bold print in the configuration file. The colour parameters are also shown, along with the screen components they apply to.

Measurement of passive bandpass		
1	*; dma channel*	
2.0000000000000E+0001	*; sweep start frequency*	
2.0000000000000E+0004	*; sweep stop frequency*	
100	*; sweep points*	
1.0000000000000E+0001	*; reference impedance*	
0	*; sweep type*	
1	*; configuration*	
0	*; a selected function*	
-5.0000000000000E+0001	*; a minimum*	
0.0000000000000E+0000	*; a maximum*	
1	*; b selected function*	
-1.8000000000000E+0002	*; b minimum*	
1.8000000000000E+0002	*; b maximum*	
15	***; color 1***	***Curve A***
13	***; color 2***	***Curve B***
8	***; high f line color***	***Vertical graticule and measured values***
12	***; low f line color***	***Vertical graticule without measured values***
13	***; lin f line color***	***Horizontal graticule***
14	***; param color***	***Parameter settings***
8	***; back color***	***Background colour***
14	***; marker text color***	***Cursors and text***

0 ; black	*10 ; bright green*
1 ; blue	*11 ; bright cyan*
2 ; green	*12 ; bright red*
3 ; cyan	*13 ; bright magenta*
4 ; red	*14 ; yellow*
5 ; magenta	*15 ; white*
6 ; brown	
7 ; bright grey	
8 ; dark grey	
9 ; bright blue	

APPLICATION NOTE

The content of this note is based on information received from manufacturers in the electrical and electronics industries or their representatives and does not imply practical experience by *Elektor Electronics* or its consultants.

stereo digital volume control

A Crystal Semiconductor application

Although the stereo digital volume control Type CS3310 from Crystal Semiconductor is designed primarily for audio systems, it may also be used to upgrade existing systems by providing programmable level control. These applications may include automatic test equipment and industrial control. It contains a 16-bit serial interface that controls two independent, low-distortion audio channels. The simple 3-wire interface provides daisy-chaining of a number of CS3310s for multi-channel audio systems. The device includes an array of well-matched resistors and a low-noise active output stage that is capable of driving a 600 Ω load. The CS3310 operates from ±5 V supplies and has an input/output voltage range of ±3.75 V.

By Gregor Kleine

The CS3310 is a stereo digital volume control designed for audio systems. The levels of the left-hand and right-hand analogue input channels are set by a 16-bit serial data word; the first eight bits address the left-hand channel, the other eight, the right-hand channel. Resistor values are decoded to 0.5 dB resolution by an internal multiplexer for a total attenuation range of –95.5 dB. An output amplifier provides a programmable gain of up to 31.5 dB in 0.5 dB steps. This results in an overall 8-bit adjustable range of 127 dB

Once in operation, the CS3310 can be brought to a muted state with the mute pin, MUTE, or by writing all zeros to the volume control registers.

Very few external components are required to support the CS3310: normal power supply decoupling components are all that is required as shown in **Figure 3**.

INSIDE THE CS3310

The internal circuit of the CS3310 is shown in **Figure 1**. Each of the two identical channels consists of a variable 0 dB to –95.5 dB attenuator followed by a non-inverting amplifier. This amplifier has a programmable gain of 0 dB to 31.5 dB. This is followed by the digital control circuit, consisting of a 16-bit shift register/latch and a serial to parallel register.

Mute and offset calibration

The MUTE input allows the CS3310 to be muted and initiates an internal offset calibration. The device should remain muted until the supply voltages have settled to ensure an accurate calibration. The offset calibration minimizes internally generated offsets and ignores offsets applied to the AIN pins. MUTE disconnects the internal buffer amplifiers from the output pin and terminates AOUTL and AOUTR to ground with 10 kΩ resistors. The mute is actuated with a zero crossing detection or a 100 ms timeout to eliminate any audible clicks or plops. The mute can also be actuated by sequentially ramping down all zeros from the current volume control setting to the maximum attenuation.

Noise-free level transitions

In each channel, a high level on ZCEN (zero crossing enable pin 1) enables the zero crossing function, while a low level on this pin disables the function. The gain/attenuation changes of the CS3310 occur at zero crossings only, which eliminates glitches during level transitions, and there are, therefore, no audible artifacts in the analogue output signal during such changes—see **Figure 2**. The zero crossing for the left-hand channel is the voltage potential at the AGNDL (left-hand channel analogue ground, pin 15), while the voltage potential at the AGNDR

Table 1. Technical characteristics	
Adjustable range	–95.5 dB attenuation; +31.5 dB gain
Resolution	0,5 dB/step
Frequency range	DC - 100 kHz
Frequency response	< ±0,01 dB
Dynamic range	> 110 dB
thd + noise	0,001 % (typical)
Channel separation	> 100 dB
No. of channels	2, independently controlled
Mute damping	> 100 dB
Mute duration	min 2 ms (for offset calibration)
Interface	serial (data, clock, chip select)
Clock	Max. 4 MHz
Input impedance	10 kΩ
Input voltage range	max. ±3,75 V
Output voltage range	max. ±3,75 V into 600 Ω
Output current	max. 20 mA, short-circuit-proof
Supply voltage	±5V
Current drain	5 mA (typical)
Power consumption	50 mW (typical)
Operating temperature	0 - 70 °C
Package	SOL16 (CS3310-KS), DIL16 (CS3310-KP)

(right-hand channel analogue ground, pin 10) defines the right-hand channel zero crossing.

Time-out facility

A volume control change occurs after chip select latches the data in the volume control data register and two zero crossings are detected. If two zero crossings are not detected within 100 ms of the change in CS, the new volume setting is implemented. The zero crossing enable pin, ZCEN, enables or disables the 100 ms timeout circuit.

Analogue inputs and outputs

The maximum input level is limited by the common-mode voltage capabilities of the internal op amp. Signals approaching the analogue supply voltages may be applied to the AINL and AINR (analogue left-hand and right-hand channel inputs, pins 16 and 9) if the internal attenuator limits the output signal to within 1.25 V of the analogue supply rails.

The outputs are capable of driving 600 Ω loads to within 1.25 V of the analogue supply rails and are short-circuit protected to 20 mA.

Earthing and power supply decoupling

A complete circuit with manufacturer recommended decoupling capacitors is shown in **Figure 3**. As with any high-performance device which contains both analogue and digital circuitry, careful attention to power supply and grounding arrangements must be observed to optimize performance. Thus, VA+ should be connected to a clean +5 V supply and VA– to a clean –5 V supply. The digital circuits are powered by VD+, which is also connected to VA+ to minimize latch-up possibilities. All supply lines should be decoupled by capacitors as close to the CS3310 pins as possible. Note that the analogue and digital ground planes are isolated, which is facilitated by the pinout of the CS3310.

Serial data interface

The CS3310 has a simple, 3-wire interface that consists of three inputs: SDATAI (serial data input, pin 3), SCLK)serial data clock, pin 6), and CS (chip select, pin 2), SDATAO, serial data output, pin 7) enables the user to read the current volume setting or provide daisy-chaining of a number of CS3310s.

The 16-bit serial data is formatted MSB first and clocked into SDATAI with CS low as shown in **Figure 4**. The data is latched by the leading edge of CS and the analogue output levels of both channels are set. The existing data in the volume control data register is clocked out SDATAO on the trailing edge of sclk. This data can be used to read current gain/attenuation levels or to daisy-chain a number of CS3310. The proper setup and hold times for CS, SDATAI, SCLK, and SDATAO are shown in Figure 4. SLCK and DATAI should be active only during volume setting changes to

1

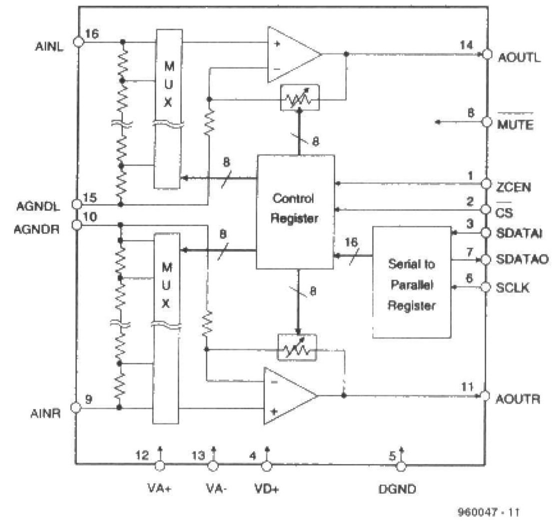


Figure 1. Internal circuit of the CS3310.

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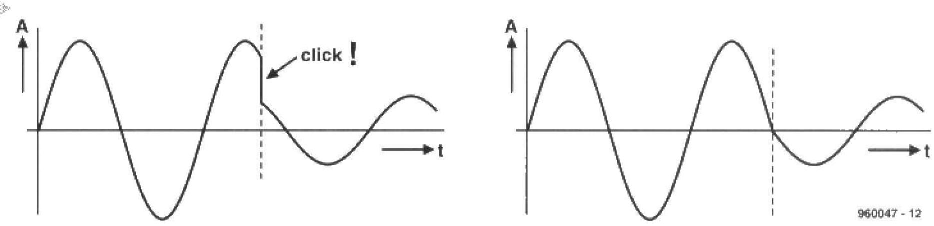


Figure 2. (left – no zero crossing) voltage steps result in audible zipper noise when volume is changed; (right – with zero crossing) no voltage steps, no noise.

Figure 3. Standard application circuit of the CS3310.

3

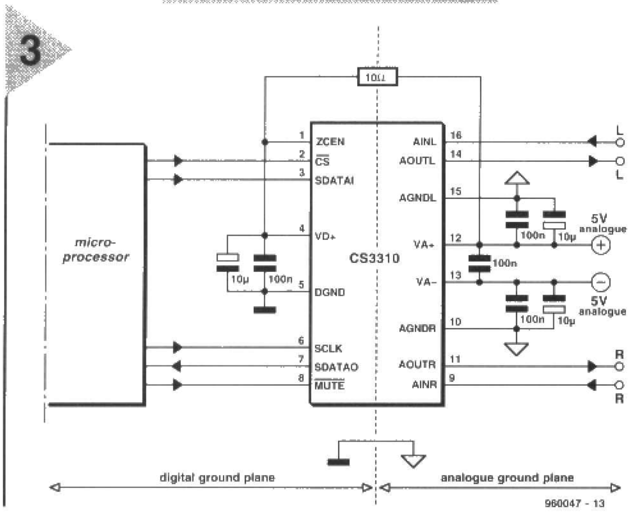


Figure 4. Serial port timing diagram.

L0 = left-hand channel LSB *R0 = right-hand channel LSB*

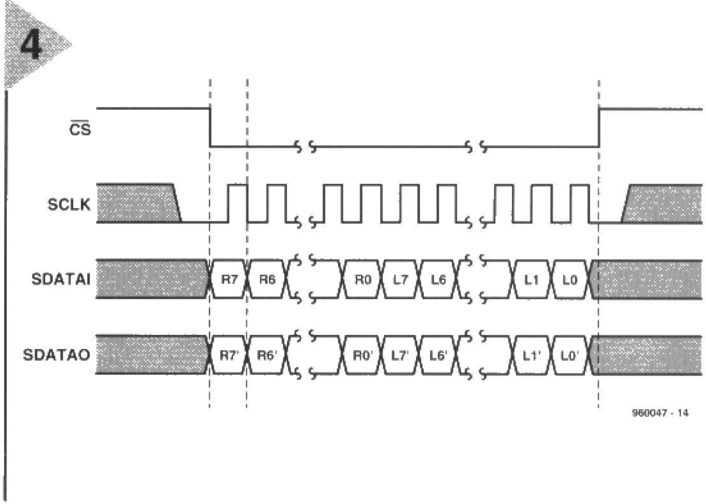
L7 = left-hand channel MSB *R7 = right-hand channel MSB*

SDATAI is latched internally at the leading edge of sclk

SDATAO transitions after the trailing edge of sclk

SDATAO bits reflect the data previously loaded into the CS3310

4



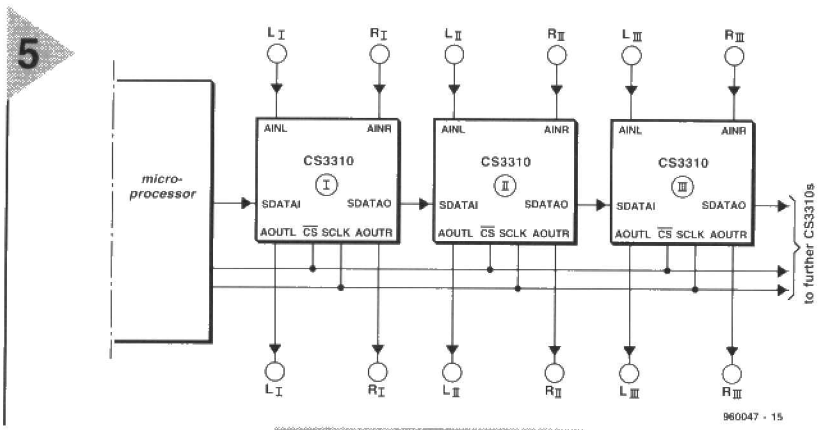


Figure 5. Daisy-chaining diagram.

Table 2.
Input code definition

Input code (either channel)	Gain or attenuation (dB)
11111111	+31,5
11111110	+31,0
11111101	+30,5
....	....
11000000	0
....	....
00000010	–95,0
00000001	–95,5
00000000	software muting

achieve optimum dynamic range.

DAISY-CHAINING (CASCADING)

Digitally controlled, multi-channel audio systems often result in complex address decoding which complicates PCB layout. This is greatly simplified with the daisy-chaining capability of the CS3310.

In single device operation, volume control data is loaded into the 16-bit shift register by holding the CS pin low for 16 SCLK pulses and then latched on the leading edge of CS. The previous contents of the shift-register are shifted through the register and out SDATAO during the process.

Multi-channel operation is implemented as shown in **Figure 5** by connecting the SDATAO of device no. 1 to the SDATAI of device no. 2. In this manner, a number of CS3310s can be loaded from a single serial data line without complex addressing schemes. Volume control data is loaded by holding CS low for 16*n* SCLK pulses, where *n* is the number of CS3310s in the chain. The 16 bits clocked into device no. 1 on SLCK pulses 1–16 are clocked into device no. 2 on SCLK pulses 17–32. The CS3310s are updated simultaneously on the leading edge of CS following 16*n* SCLK pulses.

Although the CS3310 is tolerant to power supply variations, the device will enter a hardware mute state if the power supply voltage drops below about ±3.5 V.

MISCELLANEOUS

Since the earlier described offset calibration is effective only when the input signal is disconnected, external offset voltages should be avoided. These will not be compensated and thus lead to zipper noise (pops and clicks) when the gain/attenuation is being changed. Some relief is given by coupling the input signal capacitively. Since the input resistance is relatively high (10 kΩ), a 10 μF capacitor will lower the threshold of the noise to –3 dB at about 1.6 Hz.

If the CS3310 is called upon to drive a 600 Ω load, the distortion factor, relative to a lightly loaded condition, clearly increases by about 0.01 per cent. Thus, if it is desired to increase this by another few hundredths of a per cent, the load should not be lower than about 2 kΩ. It may also be useful to place a buffer amplifier between the VS3310 and the load.

APPLICATIONS

In addition to the standard application shown in Figure 3, the CS3310 can be used as the basis for a complete microcontroller-driven stereo amplifier as shown in **Figure 6** or as a microcontroller-driven audio mixer as shown in **Figure 7**.

[960047]

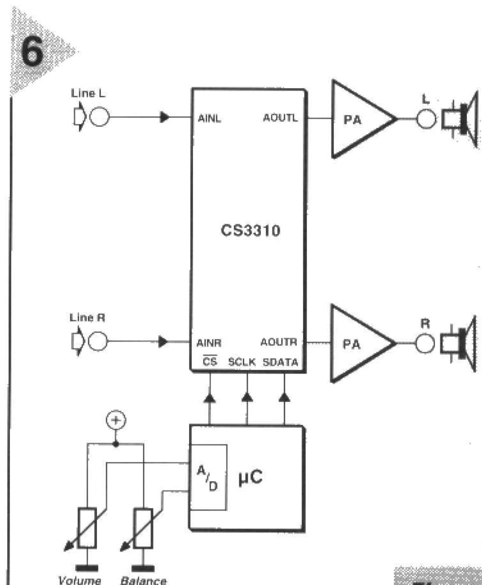


Figure 6. Microcontroller-driven stereo amplifier.

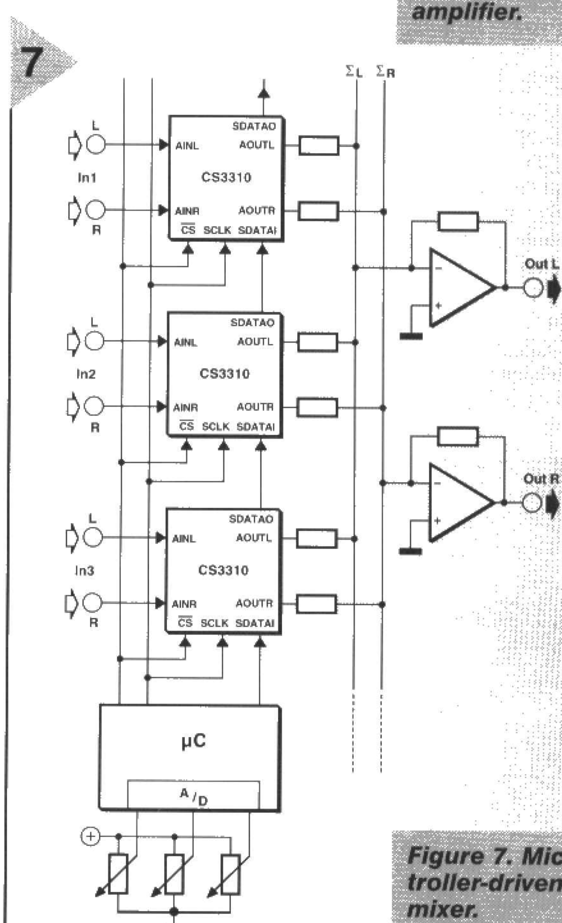
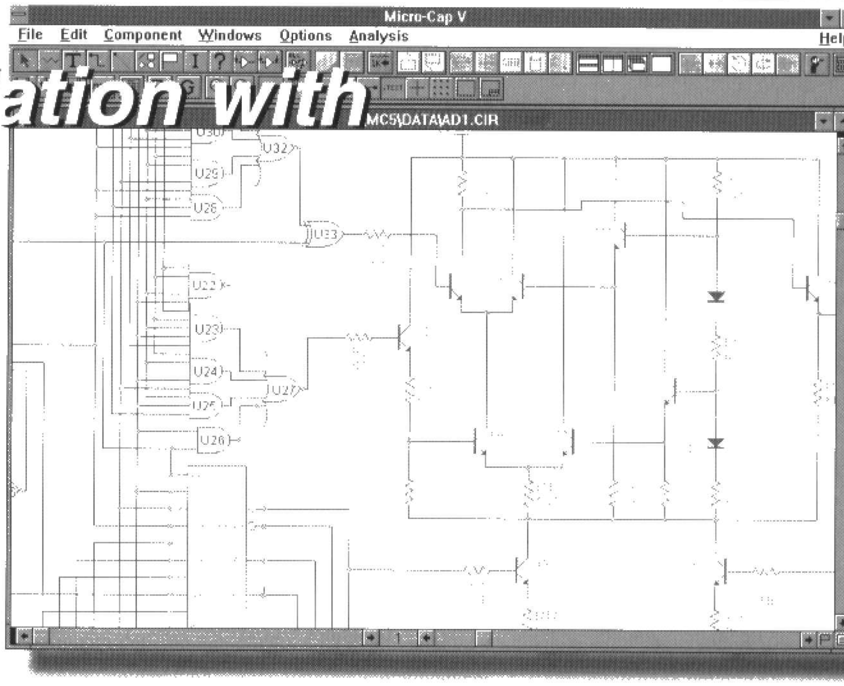


Figure 7. Microcontroller-driven audio mixer.

software for electronics

circuit simulation with Micro-Cap



Micro-Cap is an electronic circuit simulation program which has been around for many years. Recently, it reached version 5. Right from its earliest version, Micro-Cap was different from other simulation programs by allowing circuits to be entered graphically, allowing less experienced electronics designers to become rapidly conversant with the program (after some getting used to, of course). This month's *software for electronics* page introduces the new version, V (for 'five'), and also discusses a student version of release IV, which is interesting because of its superb price/performance ratio.

Around the globe, there are dozens of companies involved in developing and marketing simulation programs for electronic circuits. Most of these programs are based on Spice, which has become a standard in this field. Not surprisingly, there are many programs whose name contains the component 'Spice'.

About ten years ago, when simulation programs became popular alongside PC use in general, their main disadvantage was that the user had to be thoroughly familiar with the entire simulation process. That was mainly because the user had to use a word processor to compile a so-called netlist which contained information about all the parts used in the circuit, their junctions, and their electrical characteristics. Most Spice-based programs still work in this way, albeit that there is help in the form of component libraries and/or circuit drawing programs which generate the netlist when the graphics input is finished. With the aid of a number of modules, you advance from circuit diagram to netlist, and then have the program perform its calculations and display the results as graphics.

Right from its introduction, Micro-Cap (from U.S.A. based Spectrum) used an integrated structure where schematics drawing, simulation and display were indivisible. Over the years, Micro-Cap has evolved into an extremely user-friendly and reliable program used by thousands of electronics design engineers, despite its small deviations from the Spice standard.

Version V

Micro-Cap version V was introduced recently. This version offers mixed-mode simulation under Windows. Version V is a real 32-bit application program which operates under Windows 3.1, Windows NT and Windows 95. The program contains a schematic editor, a mixed-mode simulator with simultaneous graphics display and a separate parameter calculation program for modelling components on the basis of information found in manufacturers' datasheets.

In addition to the usual linear and non-linear analyses in the time and frequency domain, Micro-Cap V also does calculations on d.c. settings and extensive checks for worst-case, Monte Carlo, Fourier, noise, distortion, time delay and Nyquist. Furthermore, it is possible to enter purely mathematical functions which may be used to evaluate, among others, control systems and stability criteria.

With the exception of the Model utility, all functions are contained in a single program, which greatly simplifies the practical use of Micro-Cap V. Up to 15 curves may be displayed simultaneously with junctions on the screen.

The extensive library that comes with Micro-Cap V contains over 7,500 component models, including about 1,200 models of digital circuits. From now on, Micro-Cap also endorses the standards set by PSpice and Spice3, allowing Spice models offered by semiconductor manufacturers to be used without problems.

As regards the system configuration, the minimum requirements for Micro-Cap V are an 80386 CPU with maths co-processor, 8 MBytes RAM and about 12 MBytes free space on the hard disk. The program is protected against illegal use by means of a dongle which is inserted into the parallel printer connector (Centronics port) on the computer. The retail price of Micro-Cap V will be around £2,000.

Student version

The developers of Micro-Cap, Spectrum, got wide publicity from the student versions of their programs. These versions are limited in respect of the number of component junctions (nodes) that can be entered. These student versions are, however, great for simulating smaller circuits. They cost very little, in this case, around £40. Computer books publisher Addison-Wesley teamed up with Spectrum for

the production of a book on Micro-Cap III and IV, complete with student-level software. This combined package gave lots of potential users in schools and colleges the opportunity to acquire a powerful circuit simulation program together with a clear manual. Version IV in particular offers lots of features, and comes highly recommended to any electronics designer until a student version of version V is released.

The 'Student Edition' of Micro-Cap IV offers practically all features of release V – only the Model utility is not included. The number of component junctions is limited to 50. In practice, that is not a serious limitation, however, because it still allows almost any regular electronic circuit to be simulated. Although the program runs under DOS rather than Windows, it does feature a Windows-like graphics user interface (GUI) with *ditto* operation.

Drawing a circuit diagram ('schematic') simply means selecting the appropriate components, and dropping them at the right positions on the screen. Next, the components are interconnected, and certain junctions may be given labels. You are then ready to run an a.c., d.c. or transient analysis.

The 'probe tool' is a separate mode which enables you to get a quick view of a waveform at any component junction in the circuit diagram. The Monte Carlo analysis gives you an opportunity to foretell the effects of component tolerances on the operation and performance of the circuit. Futhermore, Micro-Cap version IV offers the possibility to read and write Spice files.

The book that comes with the Student Edition of version IV excels in the clear structure which guides the beginning user through the program in a step-by-step fashion. Having gone through the book you may not know all the ins and outs of the program, although most basic functions will be familiar by then. It is strongly recommended to study the various examples that come with the program package. They give good insight into the function and structure of a lot of features.

In conclusion, we are convinced that the Student Edition of Micro-Cap IV is a professionally-geared simulation program which can be obtained at a very reasonable price.

(965036)

Further information on Micro-Cap may be obtained from

Spectrum Software, 1021 S. Wolfe Road, Sunnyvale, CA 94086, U.S.A. Tel. (+1) 408 738-4387, fax: (+1) 408 738-4702.

***The Student Version of Micro-Cap IV** by Michael S. Roden is published by The Benjamin/Cummings Publishing Company, ISBN 0-8053-1718-X.*

CONSTRUCTION GUIDELINES

Elektor Electronics (Publishing) does not provide **parts and components other than** PCBS, fornt panel foils and software on diskette or IC (not necessarily for all projects). Components are usually available form a number of retailers – see the adverts in the magazine.

Large and small values of components are indicated by means of one of the following prefixes :

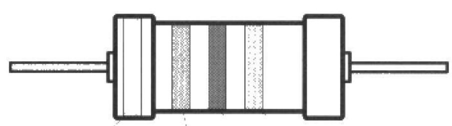
E (exa) = 10^{18}	a (atto) = 10^{-18}
P (peta) = 10^{15}	f (femto) = 10^{-15}
T (tera) = 10^{12}	p (pico) = 10^{-12}
G (giga) = 10^{9}	n (nano) = 10^{-9}
M (mega) = 10^{6}	μ (micro) = 10^{-6}
k (kilo) = 10^{3}	m (milli) = 10^{-3}
h (hecto) = 10^{2}	c (centi) = 10^{-2}
da (deca) = 10^{1}	d (deci) = 10^{-1}

In some circuit diagrams, to avoid confusion, but contrary to IEC and BS recommandations, the value of components is given by substituting the relevant prefix for the decimal point. For example,

3k9 = 3.9 kΩ   4μ7 = 4.7 μF

Unless otherwise indicated, the tolerance of resistors is ±5% and their rating is ⅓–½ watt. The working voltage of capacitors is ≥ 50 V.

The value of a resistor is indicated by a **colour code** as follows.



color	1st digit	2nd digit	mult. factor	tolerance
black	–	0	–	–
brown	1	1	$\times 10^{1}$	±1%
red	2	2	$\times 10^{2}$	±2%
orange	3	3	$\times 10^{3}$	–
yellow	4	4	$\times 10^{4}$	–
green	5	5	$\times 10^{5}$	±0,5%
blue	6	6	$\times 10^{6}$	–
violet	7	7	–	–
grey	8	8	–	–
white	9	9	–	–
gold	–	–	$\times 10^{-1}$	±5%
silver	–	–	$\times 10^{-2}$	±10%
none	–	–	–	±20%

Examples:
brown-red-brown-gold = 120 Ω, 5%
yellow-violet-orange-gold = 47 kΩ, 5%

In **populating a PCB**, always start with the smallest passive components, that is, wire bridges, resistors and small capacitors; and then IC sockets, relays, electrolytic and other large capacitors, and connectors. Vulnerable semiconductors and ICs should be done last.

Soldering. Use a 15–30 W soldering iron with a fine tip and tin with a resin core (60/40) Insert the terminals of components in the board, bend them slightly, cut them short, and solder: wait 1–2 seconds for the tin to flow smoothly and remove the iron. Do not overheat, particularly when soldering ICs and semiconductors. Unsoldering is best done with a suction iron or special unsoldering braid.

Faultfinding. If the circuit does not work, carefully compare the populated board with the published component layout and parts list. Are all the components in the correct position? Has correct polarity been observed? Have the powerlines been reversed? Are all solder joints sound? Have any wire bridges been forgotten?

If voltage levels have been given on the circuit diagram, do those measured on the board match them – note that deviations up to ±10% from the specified values are acceptable.

Possible corrections to published projects are published from time to time in this magazine. Also, the readers letters column often contains useful comments/additions to the published projects.

Current amplification

Dear Editor— Many audio output amplifiers, such as the 'hexfet upgrade' (Sept. 95) use BD139/BD140 driver pairs. However, electronics retailers normally have BD139-10 or BD140-16 in stock. Have these the same characteristics as the ones used in your project?

R. Merz, Germany

The suffix of these, and many other, transistors, indicates the current amplification group. The suffix 10 indicates a typical current amplification of ¥100 (min ¥63, max ¥160) for a collector current of 150 mA. The suffix 16 indicates a current amplification of ¥160 (min ¥100, max ¥250). The absence of a suffix means that the current amplification is 40–160. The latter values are taken into account in our projects when the transistors have no suffix. If you want to use a pair, make sure that their current amplification is the same (or very nearly so).

[Editor]

Flash programmer in China

Dear Editor—I work current in Hangzou in China. For a course for local technicians, we built the '89C51 flash programmer' (May 1995). We have a problem with the Atmel microcontroller: it reads (ic code), but does not program. We have experimented with various terminals programs and connection cables without success. The most frequent error message is a time out error.

W. Noack (China)

The most likely cause of the problem is that the computer does not send data to the programmer. To find out why not, check with an oscilloscope or logic analyser whether data is present on pin 3 of 9-way sub-D connector K1. The level at pin 8 (cts) of K1 determines whether the computer sends data. A value of +12 V enables the transfer, whereas a negative level stops the data. You need to check whether the cts signal from K1 actually arrives at the relevant pin of the sub-D connector in the computer. In case of doubt, temporarily short-circuit these pins with a length of circuit wire. If data are being sent and the cts switching line works all right, the transfer via the serial connection is ok.

[Editor]

PCM1710 redesign

Dear Editor— In the 'Mini Audio Dac' (Jan 95) a PCM1710 from Burr Brown is used. Technically, this ic is very interesting, but, unfortunately, the first production batch had some weak points, such an inaccurate digital deemphasis, and the dac being switched off when the input clock fails. In the mean time, Burr Brown has brought a redesigned version of the PCM1710 which does not have these faults. I fitted a new one on the original board and the dac now functions excellently.

G. Spreth, Germany

We, too, have obtained redesigned versions from Burr Brown and tested them in the 'Mini Audio Dac' with excellent results. The best way of removing the original ic is to cut through the pins one by one with a fine cutter. The remaining stubs can be removed easily with the point of a soldering iron. After all that has been done, the solder pads should be cleaned with desoldering braid.
[Editor]

68HC11 Processor Board

I have recently built the 68HC11 processor board (April 94) and had no difficulties. However, I then tried to obtain the software from Motorola as suggested in the article, but after many attempts I had to give up owing to the expense of searching bbs at international telephone rates.

Not to be put off, I tried to obtain the software from the local Motorola bbs, again without success.

You are the only source I can now turn to since you usually provide software on diskette at a reasonable price. Can you help?

R. Williams (New Zealand)

Unfortunately, this is a lack of communication between Europe and your delightful country. The Munich Motorola bbs (MucBox) at +49 8992 103 111 have loaded all the files mentioned in the article together into a file called elekt494.zip, which has been in the directory /mc68hxx/mc68hc11 for some time now.

Since, owing to copyright, we cannot distribute the software, your best bet is to ask your local bbs operator to get the file for you from Germany. Its size is about 65 KB.

[Editor]

Delivery times

From time to time, readers complain that certain items contained in our projects and advertised in the Readers Services column are on much longer delivery than stated in that column. We endeavour to deliver orders within 2–3 weeks from receipt of order and payment, but, as stated in the conditions of sale, we cannot guarantee this.

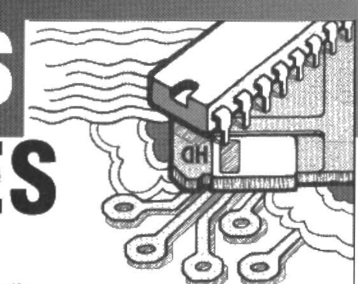
Not all readers may be aware of the fact that over the past few years there has been a world shortage of certain semiconductors, the worst affected being micropro-cessors, voltage regulators, opto isolators, logic ICS, SOT23 transistors, and CMOS EPROMS.

We are obviously concerned about complaints and take them very seriously. However, because of the world shortages, which, fortunately, are beginning to improve, we have been, and are being, let down frequently by our suppliers. As an example, certain microprocessors we ordered some time ago were promised for delivery in 18–20 weeks. Recently, we were advised, with apologies, that the quoted delivery time was optimistic and that it had to be revised to about 40 weeks.

Although we try to foresee difficulties and order well in advance of requirements, a situation as just stated cannot be foretold. Therefore, to all readers who have had reason to complain about longer than expected delivery times we offer our apologies and can only say that we are frequently just as frustrated as you are.

Meanwhile, we hope that the trend of slowly shortening delivery times will gather pace so that we may look forward to 'normal' delivery times in the not too distant future.

READERS SERVICES



ELEKTOR ELECTRONICS APRIL 1996

GENERAL

Ready-made printed-circuit boards (PCBs), self-adhesive front panel foils, ROMs, EPROMs, PALs, GALs, microcontrollers and diskettes for projects which have appeared in *Elektor Electronics* may be ordered using the order form printed opposite. The form may also be used to order books (private customers only).

- Items marked with a dot (●) following the product number are in limited supply only, and their availability can not be guaranteed by the time your order is received
- Items not listed here are not available.
- The artwork for making PCBs which are not available ready-made through the Readers Services may be found in the relevant article.
- EPROMs, GALs, PALs, (E)PLDs, PICs and other microcontrollers are supplied ready-programmed.

Prices and item descriptions subject to change. The publishers reserve the right to change prices without prior notification. Prices and item descriptions shown here supersede those in previous issues. E. & O.E.

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Payment may also be made by direct transfer from a private or business Giro account to our **Giro account No. 34 152 3801** by completing and sending to the National Giro Centre, in a National Giro postage paid envelope, a National Giro transfer/deposit form. Do not send Giro transfers direct to us, as this will delay your order.

If you live outside the UK, payment may also be made by Bankers' sterling draft **drawn on a London clearing bank, Eurocheque** made out in pounds sterling (with holder's guarantee card number written on the back), or US or Canadian dollar cheque, but such cheques, accepted at the exchange rate prevailing at the time your order is received, **must be increased by the equivalent of £15.00** to cover our bankers' negotiating fee.

If you pay by Bankers' sterling draft, make clear to the issuing bank that your full name and address MUST be communicated to the London clearing bank.

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Prices of past issues (except July/August and December), including postage for single copies, are £2.70 (UK and Eire); £3.00 (surface mail outside UK); £3.20 (air mail Europe); £3.95 (airmail outside Europe). Prices of past July/August and December issues, including postage for single copies, are £3.75 (UK), £4.00 (surface mail outside UK); £4.25 (airmail Europe); and £5.00 (airmail outside Europe).

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For information on past articles, please contact our Editorial and Administrative Office in Dorchester (telephone 01305 250995; fax 01305 250996)

COMPONENTS

Components for projects appearing in *Elektor Electronics* are usually available from appropriate advertisers in this magazine. If difficulties in the supply of components are envisaged, a source will normally be advised in the article. It should be noted that the source(s) given is (are) not exclusive — other suppliers may also be able to help.

TERMS OF BUSINESS

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Cancelled orders All cancelled orders will be subject to a 10% handling charge with a minimum charge of £2.50.

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July 1995

Article title	Order no.	Price (£)	(US$)
APRIL 1996			
U2402B Battery Charger	950120-1	12.00	24.00
Centronics Interface:			
- PCB + disk (966008-1)	960052-C	16.25	32.50
- Disk (Windows)	966008-1	6.00	12.00
PC-Controlled AF Analyser (2):			
- Software on disk	966001-1	26.00	52.00
Water Leakage Alarm		Not Available	
MARCH 1996			
Houseplant Buzzer (4 on 1 board)	950118-1	10.00	20.00
PIC-Controlled RDS Decoder:			
- PCB + PIC (966505-1)	960050-C	27.50	55.00
- PIC 16C84	966505-1	22.75	45.50
FEBRUARY 1996			
SIMM tester:			
- PCB + EPROM (966503-1)	960039-C	28.25	56.50
- EPROM	966503-1	10.25	20.50
I²C Interface for Centronics port:			
- PCB + disk (946202-1)	950063-C	20.25	40.50
- control software on disk	946202-1	12.25	24.50
Passive VU meter	950124-1	8.00	16.00
FM Receiver in SMT	936049	5.00	10.00
Icy Roads Warning	960029-1	6.00	12.00
JANUARY 1996			
SECAM-to-PAL Converter	950078-2	29.00	58.00
Copybit Inverter:			
- PCB + MACH/GAL	950104-C	44.00	88.00
- MACH/GAL		35.25	70.50
Passive Component Tester			
- PCB	960032-1	13.75	27.50
- Front panel foil		Not available	
DECEMBER 1995			
3.3-15V Power Supply	950106-1	9.25	18.50
Practice Amplifier for Guitars	950016-1	17.25	34.50
Smart Transistor Tester:			
- PCB + PIC (956502-1)	950114-C	44.25	88.50
- PIC 16C71	956502-1	35.50	71.00
Micro PLC System:			
- PCB + 87C750/51 + disk	950093-C	44.50	89.00
- 87C750/51	956514-1	24.50	49.00
- control software on disk	956016-1	10.00	20.00
Active potentiometer	954099-1	9.50	19.00
Descaler	954080-1	5.75	11.50
Active probe	954093-1	8.00	16.00
Two-way PC-Fax Interface	954033	11.75	23.50
NOVEMBER 1995			
PIP Processor:			
- PCB + 87C51 (956505-1)	950078-C	54.75	109.50
- 87C51	956505-1	30.75	61.50
FM noise squelch	950089-1	10.75	21.50
PA 300 power amplifier	950092-1	19.75	39.50
Jogging LED	950112-1	7.00	14.00
Oscilloscope prescaler	950115-1	27.75	55.50
OCTOBER 1995			
MatchBox BASIC computer:			
- PCB, 87C51, disk and Quick Reference Card	950011-C	59.25	118.50
- 87C51	956508-1	43.50	87.00
- Course diskette (DOS)	956009-1	11.50	23.00
- Quick Reference Card	950011-P	3.25	6.50
Special Autumn Supplement:			
- Experimentation board for PICs, incl. free disk for *PLC Emulation Using PIC Microcontrollers*	944105-1	17.75	35.50
SEPTEMBER 1995			
Hi-Fi headphone amplifier	950064-1	5.00	10.00
Dongle safe:			
- PCB	950069-1	12.75	25.50
- GAL IC2 (20V8)	956511-1	10.00	20.00
- GAL IC6 (22V10)	956512-1	11.75	23.50
HexFET power amp upgrade:			
- amplifier PCB	930102	12.75	25.50
- power-on delay PCB	924055	6.45	12.90
Copybit eliminator update:			
- PCB + MACH (956504-1)	950084-C	40.50	81.00
- MACH IC	956504-1	36.50	73.00
RF tone-dip oscillator	950095-1	5.25	10.50
JULY/AUGUST 1995			
Active mini subwoofer	936047	12.25	24.50
Mini robot car	936069	8.00	16.00
Simple RF function generator	950023-1	7.50	15.00
Alkali/Manganese battery charger	950056-1	6.75	13.50
Fast charger for NiCd batteries:			
- PCB + ST62T20 (956509-1)	950076-C	22.75	45.50
- ST62T20	956509-1	14.75	29.50
Simple I/O card	954074-1	11.50	23.00
6-V motive battery charger	940083-1	7.25	14.50
JUNE 1995			
Function generator:			
- PCB	950068-1	29.50	59.00
- Front panel foil	950068-F	17.75	35.50
Electronic sandglass:			
- PCB + 87C751 (946647-1)	950052-C	26.25	52.50
- 87C751	946647-1	17.75	35.50
Auto light control	950050-1	4.75	9.50
VGA distribution amplifier	950017-1	10.00	20.00
MAY 1995			
MIDI analyser:			
- PCB + EPROM (956507-1)	940020-C	34.25	68.50
- EPROM	956507-1	16.75	33.50
Programmer for 87/89C51 series Flash controllers:			
- PCB + EPROM (956644-1)	950003-C	26.50	53.00
- EPROM	946644-1	14.50	29.00
Programmable sine wave generator:			
- PCB + disk (956005-1)	950004-C	19.50	39.00
- control software on disk	956005-1	12.25	24.50
NiCd battery-quality tester:			
- PCB + ST62T15 (956506-1)	950051-C	25.25	50.50
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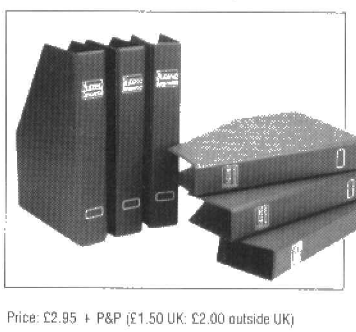

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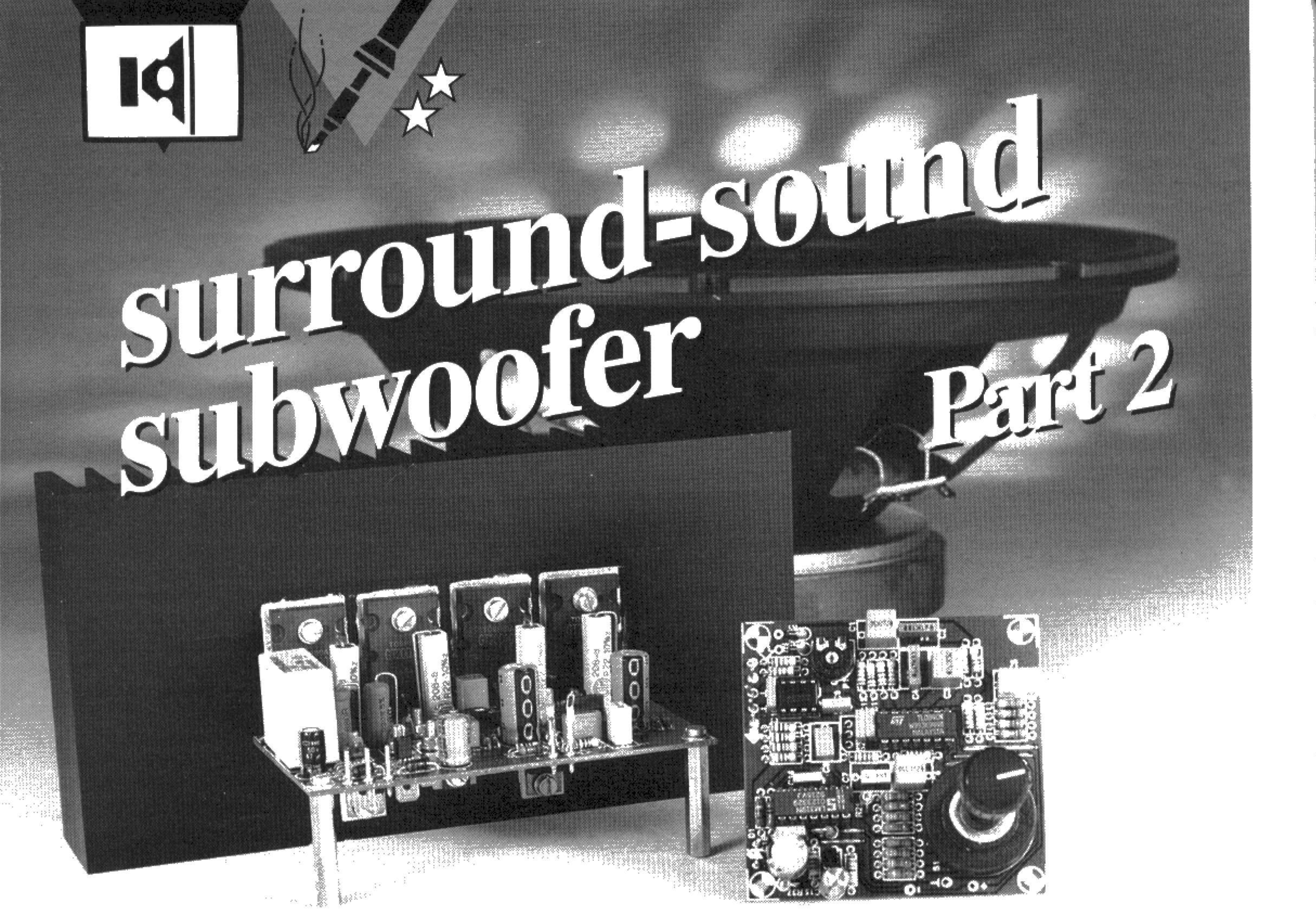

surround-sound subwoofer Part 2

This active version of the subwoofer described in last month's instalment is a plus for virtually any hi-fi system. Where the low cut-off frequency of the passive version is around 40 Hz, it is down to about 20 Hz in the active subwoofer. With its integral 240 W amplifier, it is the answer for those seeking a realistic bass foundation for their system. The more so, since its building cost is very reasonable.

Design by T. Giesberts

In Part 1 of this article, the benefit was explained that a subwoofer may have for realistic reproduction of hi-fi sound, particularly in audio-visual systems with surround sound. So, what is the value added of this active version, it may be asked. Is a cut-off frequency of around 40 Hz not sufficient for good (bass) sound reproduction?

The answer is yes and no: it depends what you want. For most music reproduction 40 Hz is a good figure: it corresponds roughly with the lowest tone of a double bass. Loudspeakers that can reproduce this frequency with good sound pressure are few and far between. Nevertheless, there are a.f. signals where 40 Hz is not sufficient. This is the case, for instance, when the canon fire in Tchaikovsky's '1812' is to be reproduced faithfully, or when thunder claps are to sound realistic. Also, the sound tracks of films like *Jurassic Park* and *Top Gun* gain in reality if the audio range goes down well below 40 Hz.

Technical data

✔ *Drive unit*	*300 mm (8 in), e.g. Monacor (SPH-300TC), KEF, Radio Shack (40-1024); Parts Express (295-240)*
✔ *Type of enclosure*	*Bass reflex*
✔ *Box dimensions*	*660×406×420mm (incl.legs) 26×16×169/16 in*
✔ *Volume of box*	*65 l*
✔ *Frequency range*	*20 Hz to 40 Hz, 50 Hz, 60 Hz or 70 Hz (as selected)*
✔ *Cross-over frequency*	*40 Hz, 50 Hz, 60 Hz or 70 Hz (as selected)*
✔ *Power output*	*245 W into 4 Ω (thd = 0.1%)*
	130 W into 8 Ω (thd = 0.1%)
✔ *THD + N at 100 Hz*	*at 1 W into 8 Ω: 0.0046%*
	at 50 W into 8 Ω: 0.001%
	at 1 W into 4 Ω: 0.007%
	at 100 W into 4 Ω: 0.0016%
✔ *Signal to noise ratio*	*90 dB linear (93 dBA) at 1 W into 8 Ω*
✔ *Damping factor*	*>400 (with 4 Ω load)*

Although the question may be asked how far down to go, to which the answer is 'the further the better', a sensible, practical limit appears to be about 20 Hz. This is because the threshold of human hearing is at around that figure. Lower frequencies are 'felt' rather than heard (to hear them would require a battery of loudspeakers that could not be accommodated in the average home. Moreover, even if it could, the possibility of damage to the building at the required volume is not imaginary).

If the cut-off frequency is set at 20 Hz, very good low-frequency reproduction is possible, while the required air displacement can be achieved with normal means. However, with a passive system, this would required an enclosure of a couple of hundred litres, and that again would be unacceptable in the average home. Therefore, what is required is an …

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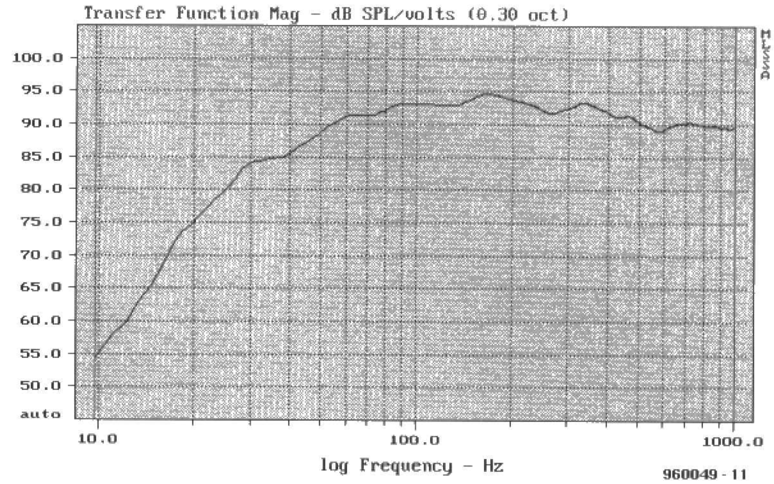

Figure 6. Frequency characteristic of the 300 mm drive unit in its base reflex box, without filter and without correction.

Active design

The most notable difference between an active and a passive loudspeaker is the amplifier in the former. In a multiple system, two or more would be needed, but fortunately only one in a subwoofer. The fact that an active design has its own amplifier makes it easily brought into line with the loudspeakers in the system into which it is being introduced.

Another beneficial aspect of an active design is that the necessary filtering can take place before the power amplifier. This filtering is carried out electronically, which has the advantage of offering virtually limitless opportunities for correcting or manipulating the frequency response of the drive unit.

In the present design, these opportunities are taken gratefully, since they allow a relatively small enclosure to reproduce frequencies down to 20 Hz. This is done by measuring the response of the drive unit in its (too small) enclosure and creating a filter with a mirror image of that response. This results in the filter compensating the irregular response of the box until a straight response curve is obtained.

The response of the passive loudspeaker described in Part 1 (using the Monacor drive unit) is shown in **Figure 6**. It will be recalled that the volume of the enclosure is 65 l. The cut-off frequency is about 45 Hz, but a close look at the curve shows that the response begins to roll off at around 85 Hz already. The curve becomes slightly steeper at about 60 Hz and even more so at 30 Hz. The latter is a direct result of the bass reflex vent: above the vent frequency, the roll off occurs at 12 dB/octave (second order) and below it, at 18 dB/octave (third order).

The active design has a basic frequency range of 20–70 Hz. To straighten the response curve, the electronic filter must have a response as shown in **Figure 7**. This curve peaks at 20 Hz (note that it begins to straighten out between 30 Hz and 20 Hz). There are four curves in the figure, because the filter is designed with four switched (upper) cut-off frequencies. This makes it easier for the loudspeaker to be combined with existing systems. Actually, we have jumped ahead slightly, because Figure 7 shows the responses of the active part of the subwoofer.

Figure 7. Response of the combined correction filter and cross-over filter. The four curves refer to (upper) roll-off frequencies of 40 Hz, 50 Hz, 60 Hz and 70 Hz.

The acoustic end result of the design is shown in **Figure 8**, which shows that the response is virtually straight between 20 Hz and 70 Hz. The solid curve is that of the actively corrected subwoofer and is obtained with a standard microphone and spectrum analyser. Comparing this curve with that of Figure 6 shows immediately the enhancement provided by the added electronics. The dotted curve is obtained when the (upper) cut-off frequency is set to its lowest value of 40 Hz.

Design considerations

The active subwoofer is based on the 30 cm drive unit specified in Part 1, and is housed in the same bass reflex box described in that instalment. The traditional cross-over filter is not used in the active design: it is re-

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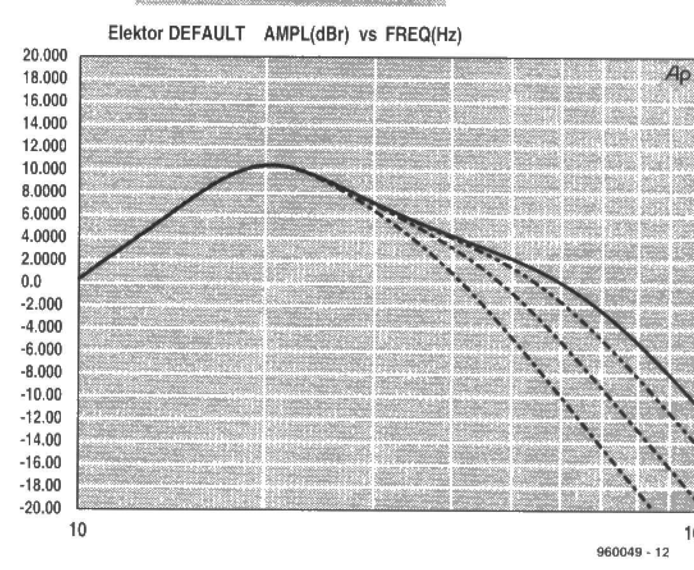

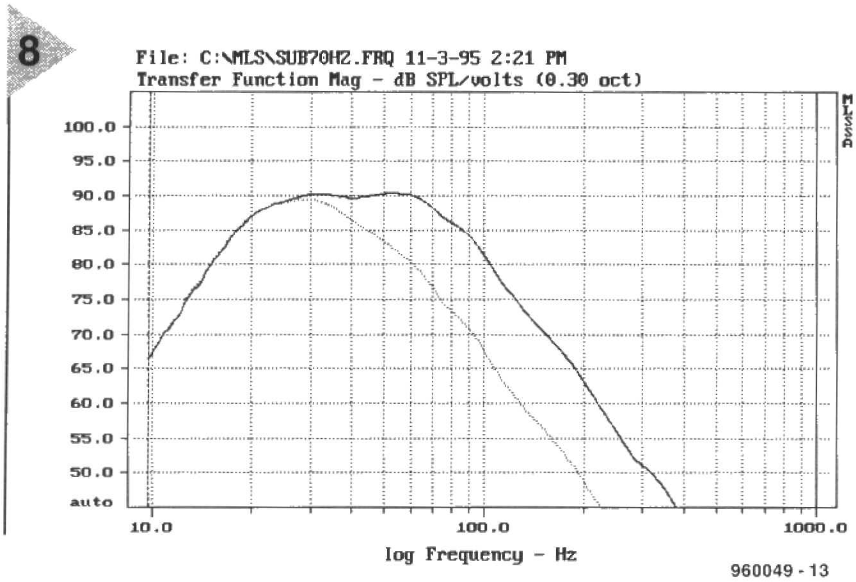

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Figure 8. After correction, the frequency response curve of the active subwoofer is straight from 20 Hz to 70 Hz. The dotted curve is measured with a roll-off frequency of 40 Hz.

placed by an electronic filter and a power amplifier.

The electronic filter is a combination of a correction filter and a cross-over filter. It straightens the response curve of the drive unit and can be switched to give one of four different (upper) roll-off frequencies.

Since the filter correction is no less than 10 dB at 20 Hz, the amplifier must provide a reasonable output power: in the present design, 240 W. The amplifier drives both voice coils of the drive unit, which are connected in parallel.

Since the electronic filter has line inputs as well as high-level inputs, the active subwoofer may be driven by a preamplifier (or via the pre-out terminals of an integrated amplifier) or via the loudspeaker terminals—see Figure 9.

The existing a.f. amplifier and the subwoofers must be linked by screened audio cable, not by loudspeaker cable.

The filter, output amplifier and the necessary power supply are housed in a common enclosure that is placed close to the loudspeaker or even fastened on to it.

The filter

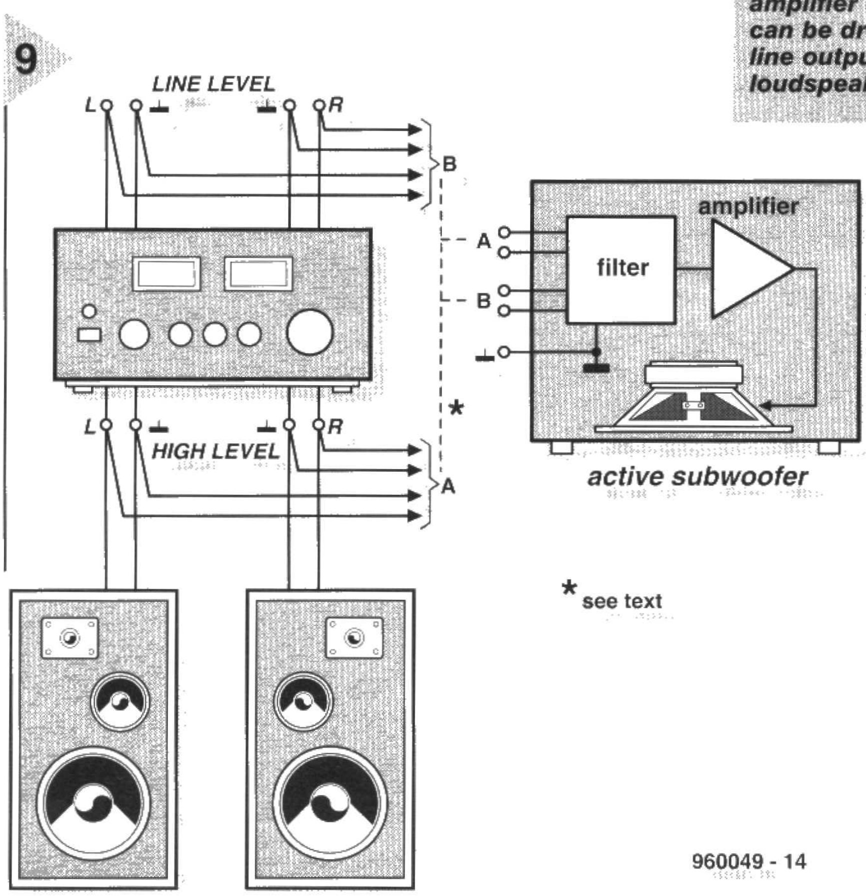
The circuit of the filter is shown in the diagram in **Figure 10**. It consists of four distinct parts: correction filter IC_{2d}, IC_{2c}; cross-over filter IC_{2b}, IC_{2a}; drive level indicator IC_3, T_1; and symmetrical power supply IC_4, IC_5.

Operational amplifier IC_{1a} functions as an up-counter for the left-hand and right-hand channels. Its amplification is varied with P_1. High-value resistors R_1 and R_2 ensure that loudspeaker signals can be processed without any difficulty.

The op amp is followed by the correction filter. This is a second-order low-pass type based on IC_{2d}. Its output is added to the unfiltered signal in IC_{2c}. Capacitors C_3 and C_4 limit the bandwidth (as does capacitor C_1 at the input of the amplifier—see **Figure 11**). The correction is enhanced by output buffer R_{28}-R_{29}-C_8, which enables the response of the loudspeaker to change gradually from second order to third order.

The cross-over filter is based on IC_{2b}. It is an active third-order low-pass Butterworth filter that can be set

Figure 9. The active subwoofer is a combination of loudspeaker, amplifier and filter. It can be driven via a line output or via the loudspeaker output.



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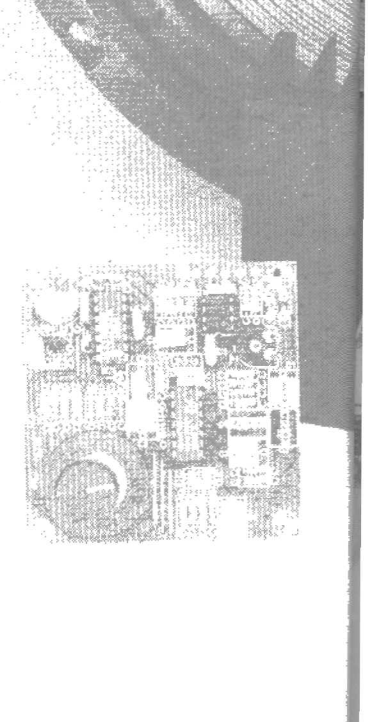

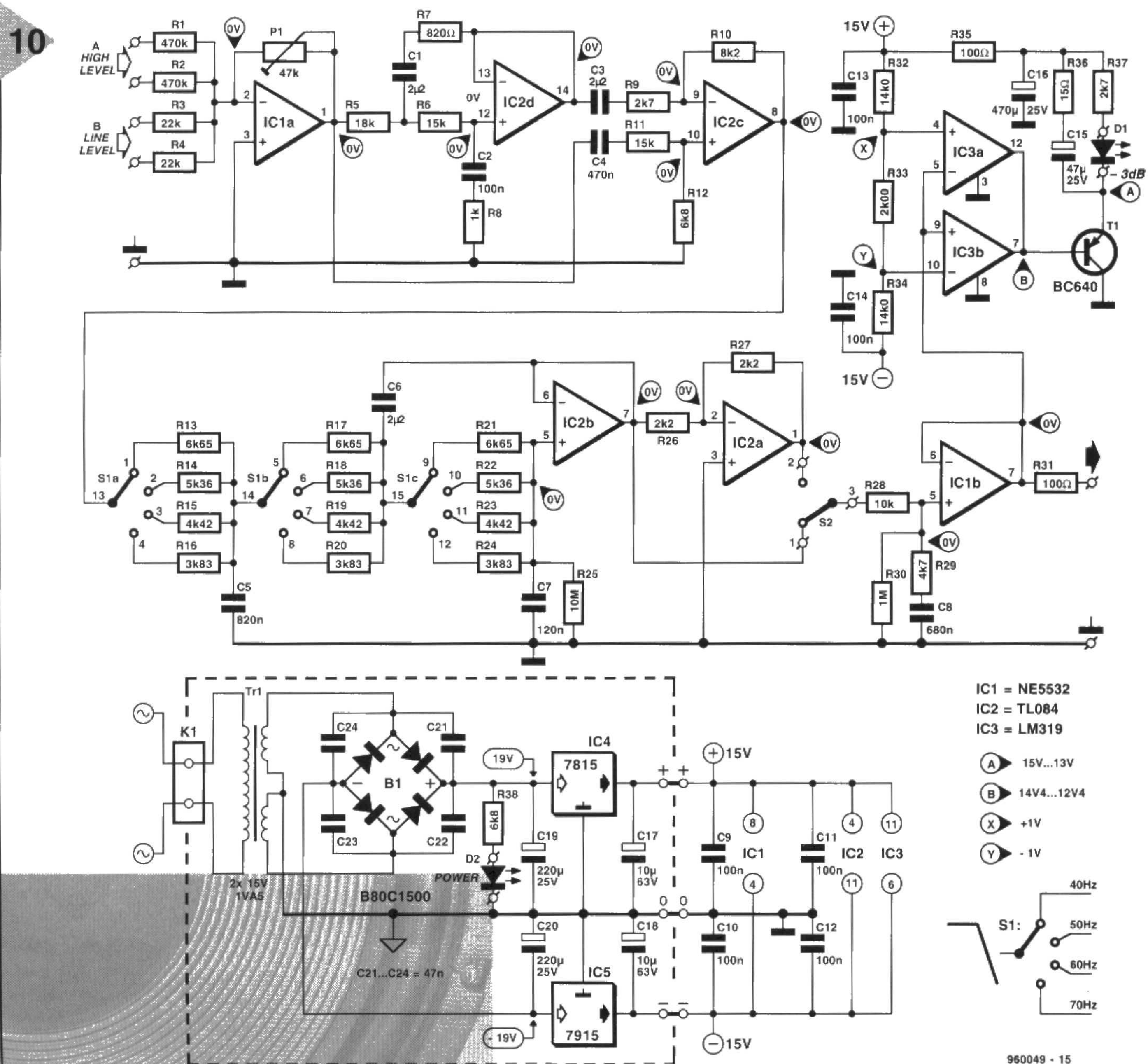

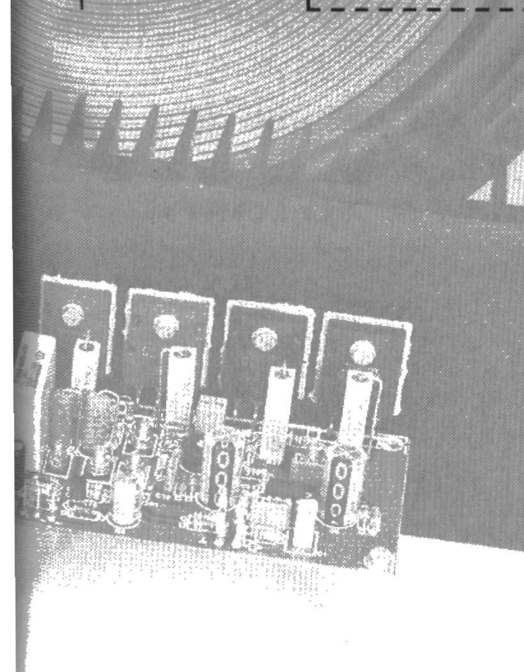

Figure 10. The circuit of the active filter is simplicity itself. The drive level indicator based on IC3 is a boon.

to any one of four different (upper) roll-off frequencies with S_1. With component values as specified on the circuit diagram, these frequencies are: 40 Hz, 50 Hz, 60 Hz, 70 Hz.

The filter is followed by inverter IC_{2a}, so that it is possible to select (with S_2) either the original signal or one that is 180° out of phase with it. This is often an advantage with certain loudspeaker systems.

The filtered signal is applied to the output via buffer IC_{1b}.

The drive level indicator, IC_3 and T_1, is intended as a protection for the loudspeaker: when the amplifier is driven to half its maximum output, diode D_1 lights. This optical signal is a warning to turn down the volume to some extent.

The indicator is based on IC_{3a} and IC_{3b}, which form a window comparator, which is designed such that the led lights when the output voltage of IC_{1b} exceeds a level of 1 Vpeak. Since the output amplifier has an input sensitivity of 1 Vrms, its drive remains about 3 dB below maximum (provided that the warning signal has been responded to).

The brightness of D_1 is enhanced by the high charging current (1 A) through C_{15} delivered by T_1. This also results in a certain amount of afterglow once the peak has passed. Network R_{35}-C_{16} decouples the power line, so that charging pulses do not cause any interference in the filter.

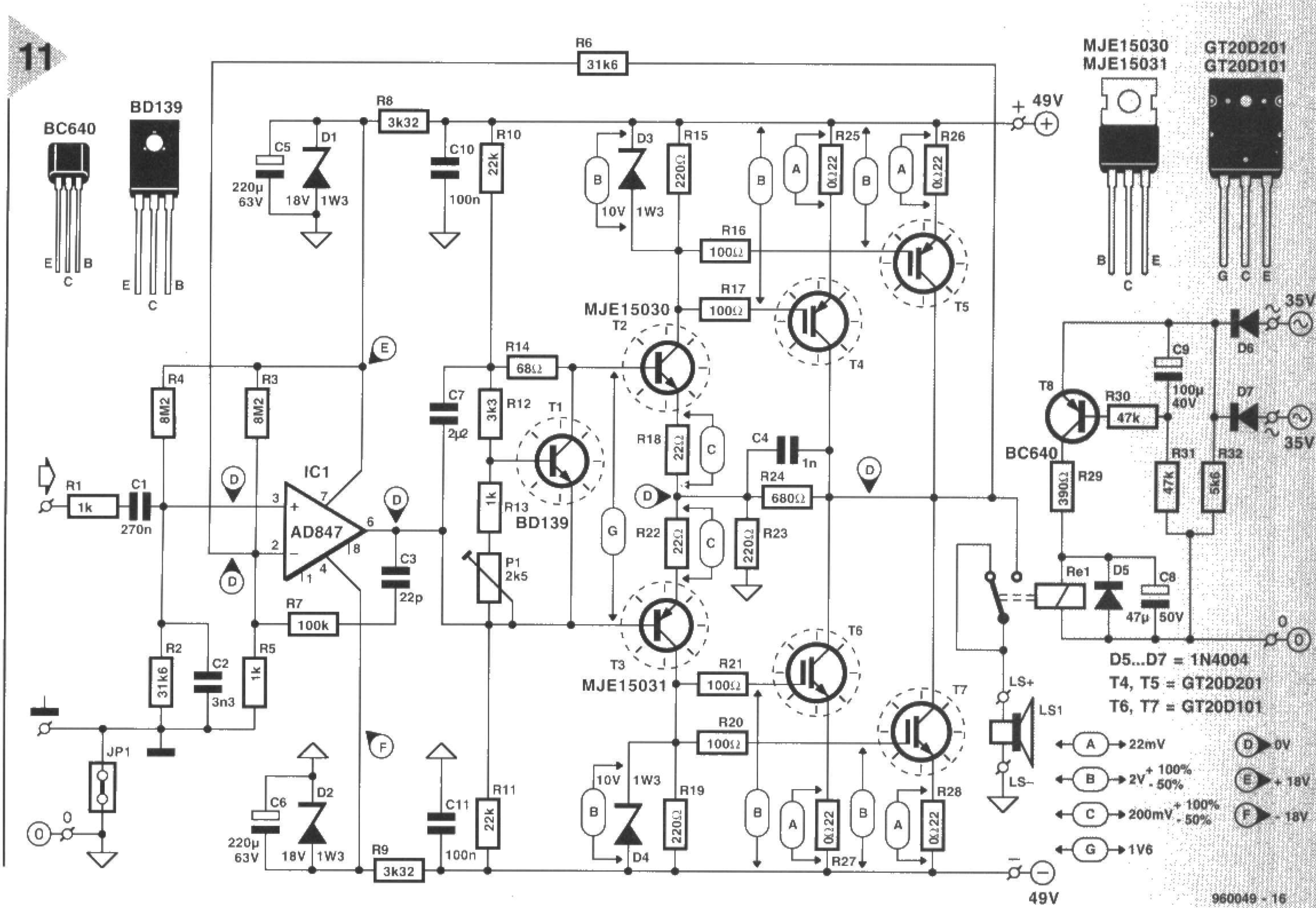

Figure 11. Since the output amplifier does not have to process frequencies above about 100 Hz, its design is spartan. In spite of this, its performance is excellent and its power is sufficient to drive the subwoofer to the very limits of its loadability.

The symmetrical 15 V power supply is a traditional design: mains transformer, bridge rectifier, smoothing capacitors and two voltage regulators, IC_4 and IC_5. Diode D_2 is the on/off indicator.

THE POWER AMPLIFIER

The output of the filter is coupled directly to the power amplifier whose circuit is shown in the diagram in **Figure 11**. Considering its output power, the amplifier is fairly compact and straightforward. The compactness is a conscious part of the design, while the simplicity is brought about by the fact that the amplifier needs to perform well only up to about 100 Hz.

The amplifier is a combination of an integrated voltage amplifier and a discrete current amplifier. Since the voltage amplifier needs to meet certain strict requirements, it is based on a very fast op amp (IC_1), the Type AD847 from Analog Devices. Its supply voltage has been made as high as feasible (±18 V) with the aid of zener diodes D_1 and D_2 to minimize the risk of overdriving.

The current amplifier is formed by two 'darlington-like' configurations, each consisting of a medium power driver, T_3/T_4, followed by two parallel-connected Insulated Gate Bipolar Transistors (igbts), T_4-T_5 and T_6-T_7. Network R_{23}-R_{24} ensures that the power stages not only provide current amplification, but also voltage amplification of ×4. This is necessary because IC_1 works from a supply of only ±18 V, whereas the output stages need to be driven to about ±45 V.

'Zener' transistor T_1 enables the correct setting of the quiescent current. For good quiescent-current stability, it is necessary that T_1 is fitted on to the same heat sink as the drivers and power transistors. The stage is designed so that it has a slightly negative temperature coefficient. This means that when the heat sink warms up, the quiescent current, set with P_1, drops a little so that the amplifier cools more quickly

Annoying and possibly damaging switch-on plops are avoided by the traditional relay, controlled by a delay circuit, in series with the loudspeaker. Transistor T_8 conducts only when C_9 has been charged to a certain level via R_{31}: that is, a few seconds after the supply has been switched on.

The delay circuit is powered directly by the secondary winding of the mains transformer. This has the advantage of the relay being deenergized immediately the supply is switched off and not after the reservoir capacitors in the power supply have been discharged.

Next month's instalment will deal with the construction.

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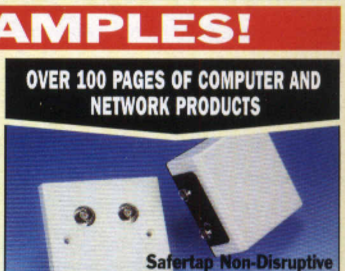

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